FORESTRY

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Edited by C. W. SCOTT

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SOCIETY OF FORESTERS OF GREAT BRITAIN

THIS SOCIETY was formed at Aberdeen in 1925 and adopted its first Constitution at Oxford in 1926. This has been modified several times and the present Constitution became operative in December 1947.

The object of the Society is to advance and spread in Great Britain the knowledge of technical forestry in all its aspects.

The activities include the publication of the journal, the holding of meetings, conferences, and excursions, and the awarding of a medal.

The membership is divided into four classes, the respective qualifications being as outlined below:

FELLOWS: Subjects of the British Crown fulfilling all four of the following requirements: (1) A degree or diploma in forestry, &c. (2) Five years of practical experience in forestry, &c. (3) Having been a Professional Associate for 5 years. (4) Having had a thesis or published article approved by the Council. Annual subscription £1. 11*s.* 6*d.* (Twenty-five guineas for life.)

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THE SOCIETY AND ITS JOURNAL

THE IMPORTANCE OF FORESTRY is being realized more and more in Great Britain. The number of foresters is increasing steadily, and a forestry profession is gradually being built up. It is intended that this Society should be representative of the profession. Those who are not engaged in the practice of forestry or the allied sciences are cordially invited to join the Society as Ordinary Members.

THE SOCIETY'S JOURNAL, called *Forestry*, is usually published twice a year, in June and December. It provides a means for the publication of the results of practice and research both in the growing of timber and in its utilization, including such basic sciences as forest physiology and ecology, forest soils, wood structure, and timber physics, and allied sciences such as forest entomology and forest mycology.

CONTRIBUTIONS may be accepted from members and others resident either in Great Britain or abroad. They should be sent to the editor, C. W. Scott, 31 Tindal Road, Aylesbury, Bucks. No article should be submitted which is being offered to any other journal for prior or simultaneous publication. References to literature should be collected at the end of the paper, and arranged alphabetically according to author's name, and numbered. In the text each reference should be indicated by its number enclosed in brackets. Each article should conclude with a summary, not exceeding 3 per cent. of the original. It is understood that the author waives any copyright or translation rights in such summaries and that their reproduction in other publications will be permitted, subject to the source being duly acknowledged. Twenty reprints of the article will be sent free to each contributor and a reasonable number may be purchased by the contributor if ordered when the proofs are returned. The Society as a body takes no responsibility for the views expressed by contributors.

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SOCIETY'S MEDAL. This may be awarded by the Society to any individual who has rendered eminent services to British forestry. Proposals for the award have to be made in the first instance to the Council by a Member of the Council. The regulations for the award will be found in Vol. XX, pp. 80, 81, and in Rule 11.

SOME RECENT DEVELOPMENTS IN FOREST RESEARCH

By W. H. GUILLEBAUD

(*Forestry Commission*)

(*Presidential address to the Society of Foresters of Great Britain, at Lincoln, Sept. 1948*)

INTRODUCTION.

THIRTEEN years ago I wrote a paper [1935 (13)] with the title 'Forest Research'. The paper was for presentation to the Fourth British Empire Forestry Conference held in South Africa in 1935, and purported to select for comment some of the more important lines of research and to indicate possible developments. In 1947 the fifth of these conferences was held in this country, and many papers were presented, covering a very wide range of subjects. As I read the symposium and listened to the discussions in the Conference, I was struck with a sense of progress in many directions. Our old friends silviculture, pathology, statistical methods, genetics, and so on were all there as before, but an alteration in emphasis was often apparent, as well as some new lines of development. It occurred to me then that it might be useful to take some of the lines of research which I had dealt with in my earlier paper and to sketch very briefly the present-day outlook. I shall have a little to say, too, on certain aspects of research, on which I did not touch in my paper, which are now assuming importance. In making this survey I am not restricting myself strictly to the papers submitted to the Conference of 1947 but shall draw on a rather wider field.

STATISTICAL METHODS.

The first subject mentioned in my previous paper was Statistical Methods. By 1935 the layouts of field trials in a form capable of statistical analysis was a commonplace in forest research, and the bad old methods of single unreplicated field plots was a thing of the past, except perhaps in the sphere of the permanent thinning plots to which I shall refer later. It is, however, the case that in the past 18–20 years there have been notable advances in the realm of statistical methods applied to forest research. I will mention only two examples. The first is the application of the factorial method [1937 (28)] to our nursery experiments. In the 1930's we in this country at least were content with simple Latin square and randomized block forms of layout, and it was only recently that under the stimulus of Dr. E. M. Crowther of Rothamsted we began to realize what a powerful weapon the factorial technique places in our hands and how much more efficient and economical in ground and effort experiments with possibly interacting factors become when the factorial method of layout and analysis is employed. The scope for the employment of factorial layouts in plantation experiments is much more restricted, and there is a lot of work to be done to devise methods of dealing with

the layout of plantation experiments, owing to the very irregular locality conditions; but I have no doubt these are capable of solution if they are tackled energetically.

The other example I want to mention is the use of random sampling. The theory of random sampling is a comparatively new branch of statistics, and there are plenty of problems still waiting to be solved, but as a practical method random sampling is coming increasingly to the fore these days. I need only remind you of the Gallup Poll, for instance. We foresters with our vast areas and immense number of trees of varying shapes and sizes—each one of which is a unit when it comes to harvesting, and not a bulk material like roots or corn—are particularly in need of reliable methods of estimating the quantity of the whole from a series of small, properly selected samples. It is satisfactory to know that the statisticians in many countries have been applying themselves to our problems. To quote only two examples, there are the line surveys carried out in Scandinavia to determine volumes and increments [1947 (21)] and, during the war, the random sample survey of the woodlands in England, carried out under the supervision of Dr. Yates of Rothamsted. Quite recently we in the Commission have started a series of random-selected sample plots for estimating thinning yields in our young plantations, which we hope will give us useful data. There is no doubt that the random sample method is going to be an increasingly useful tool in the hands of the practical forester as well as of the forest research worker of the future.

SAMPLE PLOTS AND THINNING INVESTIGATIONS.

The past decade has not seen any very striking developments in sample-plot technique. In my paper in 1935 I expressed the view that the future lay in the layout of replicated thinning plots. But as far as I know, that has not been realized. The reason is partly the difficulty of finding a large enough area of uniform crop and partly the really appalling amount of work involved in even a single series of such replicated plots. Even unreplicated sample plots involve a great deal of work, and the number of plots that a single party can cope with in the course of a year is relatively small. Much of the time required to establish a new plot or re-measure an old one is taken up in numbering the trees and in selecting and measuring sample trees. The chief object of numbering all the trees is to be able to follow the history of any given class of trees and so to know how the trees in that class have reacted to the treatment applied. That is a very interesting and useful by-product of sample-plot work, but it is only a by-product and does not contribute much direct information on rate of growth and total production, which are the primary objectives of this work. In the Research Branch we are now proposing to increase our output of established plots by laying down a proportion of new plots in which an abbreviated procedure is used. In these plots only the 100 largest trees per acre will be numbered (e.g. 25 trees in a quarter-acre plot), and no sample-tree measurements will be taken. We shall of course girth all the trees at each re-measurement, prepare the usual girth/height graph, and measure the thinnings. The main crop volume can be estimated roughly by a variety of methods, and at any time a full-scale

measurement can be made if required. A study of the development of the numbered largest trees in these plots will give us some measure of variation within the stand. In this way we hope to increase considerably our output of new plots.

The outstanding development in the realm of thinning has been the adoption by the South African Forestry Service of the revolutionary methods worked out by their Research Branch under Dr. Craib [1939 (5)]. An important paper on this subject was presented to the Conference by Dr. Craib [1947 (6)]; and Mr. W. E. Hiley, who visited South Africa recently and saw many of the plantations being managed under the new régime, has described his reactions in an admirable article in a recent number of the *Quarterly Journal of the Royal Forestry Society of England and Wales* [1948 (15)]. It would be outside the scope of this paper to discuss this question in detail, but there are one or two points I should like to stress. Firstly, there is no question but that Craib has raised an issue which cannot be burked. It was the most discussed feature of the silvicultural section of the 1947 Conference, and not a single delegate can have returned to his forestry service without resolving to re-examine his thinning régimes in the light of Craib's doctrines, and to lay down the necessary plots to enable him to test the method on his own species under his own conditions. Secondly, the early heavy thinning-cum-pruning technique which is the basis of the South African practice raises acutely the problem of the relation between rate of growth and timber quality, and so brings in the timber technologist as an essential partner in the investigation. I shall have more to say on this point later on.

GENETICS.

I approach the subject of genetics with bated breath because it is one on which the Forestry Commission, rightly or wrongly, has had what the journalist terms 'a bad press'. To a considerable extent this has been due to a misunderstanding for which I may be partly responsible. Referring back to my 1935 paper, I find that not only did I deal with tree breeding and origin of seed under two separate headings, but also separated the two subjects by interposing between them such irrelevant topics as sample-plot work and root development. In the Commission's White Paper [1943 (11)] there was a somewhat similar divorce of the two aspects of tree genetics.

Origin of seed, perhaps better termed 'provenance', with the distinguishing of local types and strains that that involves, lies at the root of all genetical work, and whatever may be the outcome of tree breeding in the sense of creating new forms of forest trees, it is certain that there are great possibilities in the application of genetical principles to forestry.

I do not think that anyone will challenge the statement that within quite recent years the forestry world has become acutely genetics-conscious. Tree-breeding stations are springing up everywhere and there is a general spirit of—dare I say—excessive optimism as to the future. I should add that the contagion has spread to this country—belatedly, I have no doubt many of you will think—and the Commission proposes to appoint as soon as possible an officer who will specialize in this branch of forest research. As evidence of current interest may be mentioned

the papers presented to the Forestry Conference by delegates from Canada [1947 (7)], and South Africa [1947 (26)]; the important Imperial Agricultural Bureau Bulletin on *Tree Genetics* by Richens [1945 (23)]; and recent publications by C. S. Larsen of Denmark [1947 (19)], Lindquist of Sweden [1946 (20)], and other Scandinavian workers.

It is worth while looking for a moment at some of the reasons for this sudden rush of interest in tree breeding. The potentialities where the poplars (*Populus* spp.) are concerned have long been fully appreciated, and it is probably true to say that, lumping all the existing tree-breeding stations together, vastly more effort is being put into raising improved strains and hybrids of poplar than into all the other species. The quick growth and easy vegetative propagation of the poplars is no doubt one of the main factors, while the success of the efforts to produce improved poplar varieties is unquestionably another. Again, the use of colchicine and other drugs for inducing polyploidy and the increase of growth associated with that condition, together with the discovery of occasional natural polyploids such as the giant triploid aspen (*Populus tremula* L.) found in Sweden, is another factor which has caught the imagination of the forester. But over and beyond all this is the fact that notable advances have been made recently in the technique of propagating many of our timber-producing forest trees. C. S. Larsen in Denmark has succeeded in various ways, notably by grafting, in getting a wide range of species to 'strike', while in Australia it has been shown that, by the use of appropriate methods, *Pinus radiata* D. Don (*insignis*) can be raised on quite a large scale from cuttings plunged in the soil [1946 (10)].

Even more important than this are the new techniques for inducing early flowering. By grafting on selected stocks and by strangulation, partial ringing, and other methods it has been possible to produce seed from selected trees of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* Karst.), oak (*Quercus* spp.), and many other species in the matter of only a few years. In the near future we shall see areas set aside for the early production of seed; and one of our chief bugbears, reliance for our seed on irregular and uncertain seed years in countries overseas, may be largely removed, to say nothing of the fact that the selection of the mother tree provides a direct means of improving the quality of our future tree crops.

The success of the agriculturist and horticulturist in selecting or breeding disease-immune strains is another potent factor in the situation. There are undoubted possibilities in this for us foresters, but there are also risks. Inherited factors are so linked together that immunity from one form of injury, say, a disease, might be purchased at the cost of increased liability to some other defect. Further, there remains the possibility that the insect pest or fungus disease, in the course of the decades occupied by the life of a single forest crop, may itself develop a more virulent strain which by attacking the supposed immune race of tree may bring to naught the best intentions of the tree-breeder.

Forestry is a long-term business and I venture to say that no responsible forest authority would authorize the use of a new hybrid or an artificially produced polyploid tree on any but a very minor scale until its value had been proved in

a wide range of localities and over at least one full rotation. This is certainly no argument against attempting to create new and improved tree species, but it is a warning against exaggerated notions of revolutionizing forestry overnight by means of tree breeding.

MYCORRHIZA.

In the past 15 years a great deal of intensive work has been done on mycorrhiza and I would refer here to two recently published summary accounts, one a semi-popular but admirable survey by Dr. Rayner [1945 (22)] and the other a more academic but most useful discussion by J. L. Harley [1948 (14)]. Harley gives references to no fewer than 132 separate papers, nearly all of which have been published since 1935, and there is, of course, an enormous earlier literature.

To the question, What is the practical significance to us foresters of those curious and intricate structures known as mycorrhizas? I regret that I am unable to give any precise answer. The fact is that this is an extremely complex problem. There are so many interrelating factors involved that so far it has been impossible to disentangle and assess separately the single factor of the mycorrhizal habit. Judging, however, from recent experimental work in this country on pine and spruce, it seems reasonably certain that if satisfactory growing conditions are provided on the planting site; in other words, if the surface soil is broken up, drained and aerated—by deep ploughing, for example—a nursery seedling or transplant stuck into the soil seems to have no difficulty in forming a mycorrhizal root system and proceeds to develop more or less rapidly according to the fertility of the soil in which it is planted. I am speaking now with reference to pines and spruces planted over a wide range of afforestation sites in Great Britain.

If the young plant has no normal mycorrhizal system, as seems to be often the case with 1-year seedling Sitka spruce (*Picea sitchensis* Carr.) raised on soil which has been partially sterilized or on soil manured with hop-waste compost, it acquires the mycorrhizal habit on its new site even when this is a very poor one, though the addition of phosphate may be necessary. Alternatively the plant may carry over with it mycorrhizal structures from the nursery in which it was raised. So for purposes of practical afforestation in this country, using plants and not direct sowing, I do not think we have any great need to worry about the possible presence or absence of mycorrhizal fungi on our planting sites. The one great desideratum is to use for planting only sturdy, well-balanced plants with a bushy fibrous root system. Now anyone used to handling plants critically knows that the desideratum just mentioned is a pretty good definition of a plant which is either well equipped with the right type of mycorrhiza or has the capacity of becoming so equipped; in other words, it is a bushily rooted plant which is well furnished with sub-lateral rootlets.

Thus, from a practical point of view, the problem is thrown back to the nursery stage—how to raise these well-rooted, sturdy plants and what part the mycorrhizas play in it. To a great extent it seems to depend on having the correct amount of the essential nutrients present, *but*, and this is a very important but, the soil must be so organized that the plant can absorb those nutrients. The mycorrhizas

appear to provide an extremely sensitive index to the condition of the soil necessary to make it a medium for raising the type of plant which the forester wants. If this view is correct, the study of mycorrhizal structures is a matter of great interest and importance to the forester.

There is, however, one important caveat; there are many different fungi which form these associations, and it is essential to have a standard based on the examination of mycorrhizas collected from vigorously growing trees from a wide range of habitats. We are fortunate in this country in having in Dr. Rayner and Dr. Levisohn, expert mycologists who have these standards for some at least of our important coniferous species and who can spot the aberrant forms, pseudo-mycorrhizas, and so on, which are otherwise so liable to confuse the issue.

There is still a vast field for research and it may well be that this will enhance the practical significance to the forester of the mycorrhizal functions.

MANURING.

So far as this country was concerned the position in 1935, as regards manuring in the forest, was that phosphate applied in the form of basic slag at the time of, or soon after, planting was found to stimulate the growth of certain species, notably Japanese larch and Sitka spruce on certain low-quality peats and poor leached mineral soils carrying a *Calluna*-rich vegetation. The stimulus varied in extent, depending on the soil conditions, but as a rule the effect was fugitive, the manured plants going back into check after a period of 4 or 5 years. A variety of other manures, including soluble nitrogenous and potassic fertilizers, was tried without substantial effect, and we were more or less reconciled to the notion that P_2O_5 was the limiting factor.

In the interval much interesting work has been published in different parts of the world, notably by Kessell and Stoate [1943 (17)] in Victoria and by Young [1940 (29)] in Queensland. The former achieved spectacular results with zinc in remedying the so-called 'short needle' disease of pines growing on poor sandy soils. They also obtained a remarkable response to applications of phosphate on other soils where pine was backward. In Queensland Young tried zinc salts as a remedy for fused needle disease without success, but found that superphosphate largely cleared up the trouble.

A certain amount of investigational work has been done both in Australia and in this country to establish trace-element deficiencies, but I do not know of any conclusive evidence to date, apart from the short-needle disease of *Pinus radiata* D. Don, due to lack of zinc. On the whole, trees appear to be very efficient collectors of the trace elements required for normal vegetative growth, except perhaps when growing on lime-rich soils.

Of recent years the focus of interest in manuring has shifted in British forestry from the forest to the nursery, and here we have been fortunate in having the active co-operation of Dr. M. C. Rayner and of Dr. E. M. Crowther. They are both members of a sub-committee, with Professor F. T. Brooks, F.R.S., of Cambridge, as Chairman, appointed by the Commission's Advisory Committee on Forest Research to study the problem of tree nutrition. Dr. Rayner approaches

the problem largely from the biological angle, stressing the importance of mycorrhiza as indicating a healthy, properly balanced condition of the soil. Dr. Crowther, on the other hand, is concerned in the first place to establish the nutrient requirements of the seedlings and their response to varying quantities and forms of organic manures and inorganic fertilizers. This work is still in its preliminary stages, but it is proposed soon to publish an interim report.

An offshoot of these more or less fundamental studies on tree nutrition, and also in its very early stages, is some interesting work on the partial sterilization of nursery soils. The soils of permanent nurseries which have been used for a number of years for raising trees tend to go 'wrong'. Analysis of them reveals no deficiency in nutrients, but the seedlings produced are small and poorly rooted. If such soils are steamed or treated with formaldehyde solution, the result is sometimes a remarkable increase in the size and root development of the seedlings. The response to the treatment varies greatly on different soils and there are many unexplained features, but where it is successful the results are often spectacular.

Another point of interest arising from the work of the Brooks Committee has been the realization that certain species, notably Sitka spruce (*Picea sitchensis* Carr.), are very sensitive to the degree of acidity of the soil, functioning best when the soil is fairly acid (round about pH 5·6), and that in a number of our nurseries we have inadvertently raised the pH to round the neutral point, or even made them alkaline by such treatments as applying weed composts heavily dressed with lime, or by using calcareous sand or gravel as a seed-bed covering. In some of the nurseries it seems clear that their gradual deterioration has been at least partly due to these misguided practices. Whether it is practicable to acidify such soils by the use of acids or of sulphur is a question which is now under investigation.

To sum up, we have four main lines of approach to the problem of nursery-soil fertility; the biological, with its emphasis on the major importance of the humus complex in the soil and of the correct balance being maintained between the several members of the soil micro-fauna and flora; the chemical approach, stressing the importance of balanced supply of the major nutrients, the important part that time of application may play, and the more, or less, soluble form in which the nutrients are given; the soil sterilization angle, in which there are no doubt all sorts of interactions on the chemical as well as the biological side; and lastly the selection and treatment of nursery soils so that the soil acidity is maintained at the optimum level. I hope that whoever may have the task of presenting the next paper on Forest Research to this Society will have some notable progress to report in this important line of work.

PRUNING.

A good summary of modern work on pruning has been given in *Forestry Abstracts* [1940 (9)], so good that it would be superfluous on my part to attempt to augment it. But I might say a few words on one or two aspects of the subject.

A great deal of experimental work has been done on tools, with the sort of results which we foresters have come to expect, namely, no general agreement on any one tool as the best for all purposes, but rather a finding that tools and methods have to be adapted to the particular species and conditions with which the forester has to deal. It is true, however, that for average conditions and for most species a curved saw with about six teeth to the inch is considered the most satisfactory tool. There is still controversy about the use of secateurs for brashing off the lower branches. They swear by this tool in some parts of Australia, but most investigators find it too heavy and cumbersome. Some estate owners in the west of England are now using light secateurs of an American pattern and find them most efficient. In the *Forestry Abstracts* summary mentioned above there is a reference to the development of a light-weight power-driven pole-saw in America, and others have been tried in Great Britain, but this device does not seem to have caught on generally.

The early prejudice against live pruning seems to be dying out. It is generally found that live pruned knots occlude quicker than dead ones, and it seems to be exceptional in Great Britain for fungi to attack the pruning wounds. On the other hand, in some of the African territories high live pruning of exotics has led to attack by bark beetles which are doing considerable damage.

There is some measure of agreement that the economic height for pruning lies between 15 and 20 feet, the figure of 17 feet above ground being perhaps the most generally advocated. This does not rule out the possible desirability of higher pruning of exceptional stands, where growth is rapid and there is a special market for clean, tall poles. There is also agreement that only the best dominant and co-dominant stems in a stand should be pruned.

There is one recent development in pruning methods which I should like to mention, namely, the disbudding of pines, the technique of which has been worked out by the Russian research worker, Krotkevitch, at Kiev [1939 (18)]. Disbudding, that is removal in late spring, after the buds have started to elongate, of all the lateral buds of the terminal bud whorl, starts when the trees are about 3 feet high and continues annually until the tree reaches a height of about 20 feet. The basal branches are left intact during the disbudding period and are pruned off later. This produces, of course, completely knot-free timber between 3 feet and 20 feet above ground.

Bickerstaff [1947 (2)] has recently reported on trials of this method which he carried out on *Pinus resinosa* Ait. in Canada. It appears to have worked quite well with this species, which forms single branch whorls without internodal branches. It seems to me worth trying with Corsican pine (*Pinus nigra* var. *calabrica* Schneid.) in the south of Great Britain, but with Scots pine (*Pinus sylvestris* L.) it would probably fail owing to Shoot-moth damage (*Evetria buoliana* Schiff.). On the other hand, I understand that Colonel Lilburn has used the method successfully on Scots pine in the north of Scotland where they are not troubled appreciably with *Evetria buoliana*. I think it remains to be seen how the trees react to storm winds in later life, when a normal crown is developed on the upper part of the trees.

PATHOLOGY.

Developments in this field, using the term pathology in the wider sense to cover insect-pests, have been chiefly in the applied sphere. I may mention the increasing use of the aeroplane and helicopter for distributing poison dusts, and the impetus given to use of this method of control by the discovery of the new insecticides DDT, Gammexane, and the like.

The biochemists do not appear to have succeeded yet in finding an efficient poison for many of the bark beetles which at the present time are such a serious menace to the conifer forests of a great part of Europe. Success in this endeavour would not lessen the need for good silviculture, which is the only real prophylactic for bark-beetle epidemics, but it would simplify and cheapen existing methods of control, especially the present tiresome and expensive practice of burning the beetle-infected bark, removed from trees that have been attacked.

Ever-increasing attention is being given to the possibilities of biological control by the introduction of parasites. This line of approach is being actively pursued in Canada, in particular, where a considerable measure of success has been achieved, and in that connexion I commend to your notice the excellent paper written for the Fifth British Empire Forestry Conference by J. J. de Gryse [1947 (12)].

So far I have referred only to certain aspects of research which were covered in my previous paper, but there are one or two topics, not dealt with there, which I should mention now, notably timber technology. Also there have been developments in new fields of research, which formed the subject of important papers at the 1947 Empire Forestry Conference, and call for some comment here.

TIMBER TECHNOLOGY.

As most of you know, the timber technologists of the Commonwealth gathered in force last year in this country and many important papers were presented to the Forestry Conference. The field covered was far too great to attempt to summarize here, but I would like to mention a few of what appeared to me the outstanding trends and consequences.

In the first place there is the immense increase in our knowledge of the efficient use of timber in all its forms, resulting from the *ad hoc* research carried out during the war [1947 (4) and (16)]. That may be regarded as one of the minor beneficent results of the war, to set off against its many major evils. As an outcome of this work, which includes such technique as gluing, plywood in all its forms, wood plastics, impregnated paper, &c., many improved or new uses for wood have been discovered, and its position as a raw material has been greatly strengthened in the world markets.

Secondly, though this is a matter of concern to us as a timber-importing rather than a timber-producing country, there are the great possibilities that lie ahead in the utilization of the so-called secondary or minor species in tropical forests. The Forest Products Research Laboratory at Princes Risborough is concentrating a large part of its effort on the study of these secondary timbers, working out their strength, seasoning, wood-working and other properties, to find suitable

uses to which they can be put. Success in this work may revolutionize the utilization of many of the mixed tropical and sub-tropical forests. Again it was the war which provided a new stimulus to this field of research.

Then there are the very important developments, more particularly in the United States, in the technique of pulp and fibre-board production. New processes have been found for producing kraft paper pulps of high strength values, and high yields have been obtained from such broad-leaved trees as birch (*Betula* spp.), aspen (*Populus tremula* L.), and oak (*Quercus* spp.), and conifers such as Douglas fir (*Pseudotsuga taxifolia* Brit.), and Thuya (*Thuya* spp.) [1946 (8), 1947 (3)]. Discoveries of this nature may have far-reaching effects upon our silviculture, and the next generation of foresters may find that the production of wood for pulp is one of their most important functions. Closely linked with this line of advance is the intensive research going on in different parts of the world on the utilization of wood waste and of by-products of the pulping processes, notably lignin. Success is only a matter of time. It may well be that within our own lifetime there will be a profitable market in this country for every scrap of woody tissue that can be grown.

Finally, I think everyone at the Empire Forestry Conference was impressed with the need for the closest possible liaison between the timber technologist and the forester, particularly in the sphere of research. To take merely one illustration, the validity of Craib's heavy thinning technique depends largely on the effect of rate of growth upon the structural and other properties of the timber. Thanks to an excellent piece of combined research [1947 (6) and (24)] the South African foresters are able to claim that they know the answer for the species with which they are chiefly concerned. Some other parts of the Commonwealth, including Great Britain, are not in the same happy position, and have a long way to go to make up the leeway.

To end this brief account of some of the present-day lines of forest research, I propose to mention a few aspects which have recently come to the fore.

HYDROLOGICAL RESEARCH.

A paper under this somewhat formidable title was prepared by C. L. Wicht [1947 (27)], Senior Research Officer in the Union of South Africa, for the recent Empire Forestry Conference. The object of this form of research is the study of stream flow with special reference to the land utilization of the catchment area concerned. The South African investigation arose partly out of the public fear that plantations of exotic pines, Eucalyptus, and wattles might dry up water-supplies, exhaust the soil, and even promote erosion.

Two research stations have been set up, one in the Cape Province, near Stellenbosch, and one in Natal. The main treatments to be compared in the Cape area are veld-protection, on the one hand, and afforestation with *Pinus radiata* D. Don, on the other. In the Natal Station the major treatments are afforestation with *Pinus patula* S. and C. and controlled burning with grazing.

An interesting feature of this work is the way that the afforestation is planned. In the Cape area there are six catchments, and these are being successively planted

up at intervals of 8 years. The first catchment was planted in 1940 and the last one is due to be planted in 1980, by which time the whole series will be under trees. The P. 40 area will then be 40 years old and will have reached maturity, while the plantations in the other catchments will be progressively younger. By this means the effect of increasing age can be studied in each stream, while the total effect of a full series of age classes will be demonstrated by the flow of all six streams added together. The measurement of rainfall, stream flow, &c., involved many technical difficulties, but these appear to have been overcome, and the first practical results are awaited within the next 10 years. The result will be of interest and value to foresters in all parts of the world and should settle many of the present controversies on the effect of forests upon water conservation.

FIRE HAZARD.

The assessment of fire hazard is a problem which has been engaging the minds of foresters for a considerable time. Techniques have now been worked out in Canada and the United States, and a good account of the problem is given by H. W. Beall [1947 (1)] in his paper to the Fifth Empire Forestry Conference. There is a striking table at the end of that paper which relates the number and size of the fires occurring in a certain part of Canada, over a 5-year period, with the degree of fire danger.

The salient feature of the table is the stress that it lays on the significance of the *highest* degree of fire danger. There were five degrees: extreme, high, moderate, low, and nil. In the extreme-danger group 46 per cent. of the fires occurred and the average size of the fire was 3,900 acres. In the high-danger group only 27 per cent. of the fires occurred and the average size of the fire was 1,765 acres. Thus there was a total loss of 262,000 acres in the first case, as compared with 69,000 acres in the second. The importance of fire-hazard research is obvious in the light of these figures.

AERIAL SURVEY.

The great use made of air photographs in the last war, and the technical improvements which resulted, have given a marked impetus to the application of aerial photography to a variety of forestry purposes. The most important of these at present are surveying and volume estimation in areas which are difficult of access. Much research is still required to discover the most suitable combination of film and filter to give the required information. In his paper to the Empire Forestry Conference H. E. Seely [1947 (25)] discusses some of the Canadian developments in the use of air photographs for forest surveys and indicates the lines along which the work is progressing.

At the moment the prospects for the use of air photographs in British forestry do not appear nearly as great as they are overseas. Our forest blocks are mostly too small and scattered and our site factors too varied to make special forest survey flights economic. It may be, however, that improvements in technique will alter the position later on.

MECHANIZATION.

Last but not least on my list of subjects is the almost unlimited sphere of research which has as its centre the concept of mechanization. Before the war the extraction and utilization sides of forestry were fairly fully mechanized in all except the undeveloped countries. Here in Britain we had also gone some way towards mechanizing the preparation of our bare lands for planting, that is, whenever the slope and the nature of the ground permitted the use of ploughing equipment. But now the vast rise in labour costs is forcing us to consider the possibilities of mechanization in every branch of forestry, from nursery practice to high pruning, and from the construction of forest roads to coppice utilization.

There is almost unlimited scope for research, and the Forestry Commission has made a modest start by appointing a research engineer to tackle some of the more urgent problems. In many cases, e.g. in nursery operations and preparation of ground for planting, the agricultural engineers have done much of the pioneer work, and it is only necessary to adapt their machines to our special purposes; but there are plenty of problems of a purely forestry nature which require a radically new approach. The probabilities are that there will be important developments in forestry mechanization to record before many years have passed.

May I conclude with the hope that I have succeeded in demonstrating that research is playing an active part in the world of forestry, and that in most directions useful progress has been made during the past 15 years.

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FORESTRY IN WESTERN GERMANY, 1948

By G. B. RYLE

(*Forestry Commission*)

1. THE PROBLEM.

LAST year the writer [1947 (2)] described the functions of the British staffs of the Control Commission for Germany and especially of the North German Timber Control during the first two years after the end of the Second World War. In July 1948 he had the opportunity to re-visit the country and to make a hasty tour into the French, American, and British Zones of occupation specifically to find out for the Forestry Commission what the Germans were doing to make good the losses occasioned in their forests during the Nazi régime of over-exploitation, the war years, and the post-war period of heavy fellings which were ordered by the occupying Allies for European (including German) reconstruction purposes.

The three western zones of occupation contain 14,032,000 acres of forest land, excluding the small unclassified woods of under 25 acres each, which probably increase the total area by a further 2,000,000 acres. The distribution in the separate zones under the three principal classes of ownership is:

TABLE I

Ownership	*Thousands of acres*				*Percentage of total area*
	U.S.	*British*	*French*	*Total*	
State forests . . .	3,087	1,323	950	5,360	38
Private forests . . .	1,967	1,915	553	4,435	32
Communal forests . . .	1,917	615	1,705	4,237	30
Total area . . .	6,971	3,853	3,208	14,032	100

A census conducted by the Germans at October 1946 indicates a very great abnormality in the distribution of the size-classes of timber, with a serious deficit in the larger categories (see Table II).

Great stress is laid by the German forest economists on the claim that the shortage of large-sized timber must result in the near future in the need for the country to import log or sawn timber. The data have been freely used for propaganda purposes in an endeavour to reduce or stop the fellings for export to Britain, France, Belgium, and Holland. The volumetric estimates are calculated from individual compartment and sub-compartment surveys compiled at each of the *Forstämter* (District Forest Offices), but admittedly the basis of computation has been almost entirely from standard yield tables. There was no doubt a big temptation to under-estimate the quality classes and the stocking percentages,

to strengthen the arguments in favour of a rigid conservation policy, and it is fairly certain that the figures quoted below are heavily under-estimated.

In respect of the British Zone it is seen that the largest size-class of timber amounts to a mere 3·2 per cent. by area or 10·2 per cent. by volume. It must be borne in mind, however, that the majority of the saw-mills of the zone and the

TABLE II

(Areas in thousands of acres; volumes in millions of Hoppus cubic feet, over bark)

Breast height Diameter class	*U.S. Zone*		*British Zone*		*French Zone*		*Total*	
	Area	*Vol.*	*Area*	*Vol.*	*Area*	*Vol.*	*Area*	*Vol.*
I. Under 6 in. (up to 15 cm.)								
Softwood	2,655	1,746	1,387	748	1,002	610	5,054	3,104
Hardwood	950	582	797	277	642	222	2,389	1,081
II. 6 in. to under 10 in. (16 to 25 cm.)								
Softwood	967	2,605	368	831	448	1,247	1,783	4,683
Hardwood	393	831	375	748	275	526	1,043	2,105
III. 10 in. to under 14 in. (26 to 35 cm.)								
Softwood	605	1,967	133	388	292	1,108	1,030	3,463
Hardwood	422	1,275	300	804	216	526	938	2,605
IV. 14 in. and over (36 cm. and up)								
Softwood	165	637	5	166	88	416	258	1,219
Hardwood	132	416	105	277	88	222	325	915
Clear felled	282	..	295	..	84	..	661	..
Other non-forested	390	..	88	..	73	..	551	..
Total area	6,971	..	3,853	..	3,208	..	14,032	..
Total softwood	..	6,955	..	2,133	..	3,381	..	12,469
Total hardwood	..	3,104	..	2,106	..	1,496	..	6,706

bulk of the normal consumer sizes of scantling are customarily supplied from comparatively small logs. Group III (10–14 inch B.H. diameter) comprises 12·5 per cent. by area or 28·1 per cent. by volume of the British Zone forests, though with nearly two-thirds of the quantity in hardwoods.

As far back as 1927 it is interesting to observe that in the whole of Germany the conifer forests contained only 15 per cent. by area of woods in the over-80 years age classes, and Heske [1938 (1)] states 'With conifers relatively short rotations are characteristic. This is because much of the pine is grown for mine timber and much of the spruce for pulpwood, and also because there is an increasing demand for small building timbers.' The deterioration of the larger sized timber capital during and after the Nazi régime has been exaggerated to support what is doubtless an otherwise sound argument. Germany's internal timber economy is precarious, but compared with the rest of western Europe she is still amongst the wealthiest countries.

The position since the 1946 census has deteriorated markedly on account of further heavy fellings, a more realistic appreciation of the war-seared forests, especially on the Dutch border, and not inconsiderable forest fires. In the spring of 1948 it was estimated that the following areas were 'in need of reafforestation':

TABLE III

Zone	*Devastated Thous. acres*	*Per cent. of forest land*
U.S. .	375	5·7
British .	450	12·0
French .	163	5·2
Total .	988	7·3

Concurrently Dr. Assmann, German Director of Forestry for the combined U.S./U.K. Zones, assessed the felled areas at 417,000 acres in the U.S. Zone and 652,000 acres in the British Zone. Figures secured from the *Oberlandesforstmeisters* (i.e. Directors of Forestry responsible directly to the Ministers President of each *Land*) in charge of the three *Länder* of the British Zone gave a total felled and devastated area of 615,760 acres. With such divergent data obtained from contemporary authoritative sources it is difficult to arrive at a true basis.

It may be assumed, however, that the British Zone programme, including the restoration of large areas disafforested by the Nazis for battle-training purposes, airfields, bombing and firing ranges, munition factories, &c., amounts to some 600,000 acres, together with the timely replanting of future rather less abnormal annual cuts. In addition there is a project of forming some 50,000 acres of new forest on waste land in Schleswig-Holstein, which has hitherto been the most poorly timbered *Land* in Germany. Normal fellings and replantings in the British Zone, based on pre-Nazi silviculture, would have been about 38,000 acres per annum.

The normal yield of the British Zone has not been calculated with accuracy, but it is stated to amount to some 150 million cubic feet per annum, which is equivalent to a mean annual increment of 40 cubic feet per acre on the whole forest area or of 43 cubic feet per acre if the felled areas be excluded. There is little doubt that this is an under-estimate.

The degree of over-felling since the war, as compared with a reasonably normal pre-war year, is clearly shown in the following table, which also analyses the post-war utilization and entirely refutes the statement that nearly one-half of the total coniferous stemwood is booked for export. [Wiedemann 1948 (4).]

Since the formation of the bizonal administration of the combined U.S./U.K. territories the German pleas for a reduction in the felling targets have been very sympathetically treated, as is seen from the planned target for the forest year 1947/8. Fellings for export will be greatly reduced after this forest year, by which time 113 million cubic feet, or only two-thirds of one year's increment of the

whole of the forests of the British Zone, will have been exported as a credit against food and other commodities supplied to the zone.

TABLE IV. *British Zone*

Class of produce	*Volume of fellings in millions cu. ft. Hoppus*						
	1933/4	*1945/6*		*1946/7*		*1947/8 planned*	
	(Normal)	*Home*	*Export*	*Home*	*Export*	*Home*	*Export*
Logs	102	141	5	83	69	108	39
Pitwood	17	36	*	22	*	33	*
Firewood	42	258	..	186	..	83	..
Other	..	39	..	72	..	..	..
Totals	161	474	5	363	69	224	39
Gross Totals	161	479		432		263	

* Small quantities of pitwood exported included under 'Logs'.

The enormous quantities of fuelwood consumed were the inevitable and direct result of the smashing up of the railways and the Ruhr collieries during the war. It is recognized that the urgency of the 1945/6 fuel programme arose quickly after the cessation of hostilities and had to be handled while the country was still in a state of chaos, but there was nevertheless a degree of extravagance on the part of the German forest staffs which could have been mitigated by foresight and initiative. It is admitted by the German foresters that fully half of the fuelwood prepared was from prime millable timber, largely growing in State forests. Meanwhile inferior forest growth of little incremental promise and on equally or more accessible sites remained untouched. The position was very little better in the following winter, when again vast quantities of high-grade logs were felled and split up for fire-wood; and it was often only by dint of heavy pressure from British sources that effort was concentrated on the lower-grade woodlands.

The German forest service is too rigidly divorced from the timber-consuming industries. The former is vociferous in warning of a coming internal timber famine, while the latter continues to use timber in many directions in a highly lavish manner. Such control as may have existed during war years and subsequently has been quite impotent to check wastage and even this control has now been virtually withdrawn.

The enormous building reconstruction programme which has hardly yet begun in Germany must inevitably absorb vast quantities of timber, and extravagance in home-grown supplies should be completely curbed in a manner which has never yet been attempted.

Western Germany has suffered from 15 years of over-felling, and for 8 years of that period it was impossible to maintain reafforestation. The bulk of the over-felling has been concentrated on the larger size-groups. The need now is to make good the fellings and war-devastated forests, and to endeavour by silvicultural management to accelerate the development of larger sized logs, especially in

softwoods. At the same time the average forest increment of 40–45 cubic feet per acre per annum is agreed to be a most unsatisfactory one and to be capable, on a long-term policy, of considerable improvement. Stehle [1948 (3)] quotes for Land Nord Rhein-Westfalen an average annual increment of 50 cu. ft. per acre in the State forests, 39 cu. ft. per acre in the communal forests, 44 cu. ft. per acre in the settled private forests, and only 14 cu. ft. per acre in the free private forests. In the Reichenbach district of the Black Forest (French Zone) the State forests yield 77 cu. ft. per acre, whereas the communal forests have an increment of only 20 cu. ft. per acre, according to Forstmeister Kemphler. Heske [1938 (1)] confirms that the State forests have been managed to give a sustained yield well in excess of any other class of forest ownership, and he particularly stigmatizes the miserable condition of the smaller freehold forests.

Even in the State forests the thinning practice during the past generation has been so extremely conservative that diameter increment is certainly severely retarded, even if total increment is not reduced. It was not possible to obtain any figures, but the impression was gained throughout the three zones that underthinning during the first 30 years' growth, particularly in the pine crops, was so intense that weakening and lowering of increment was resulting.

2. STAFF, ADMINISTRATION, AND POLICY.

Generally throughout the British Zone there is a very adequate staff of trained German forest officers to undertake a large programme of restoration. In Land Niedersachsen in addition to a fully employed staff of 150 *Forstmeisters* and higher grades, there are stated to be a further 600 similarly graded officers, refugees from the east, who cannot be found full employment. In Bavaria (U.S. Zone), however, qualified staffs are below the required establishment. It would not be easy for the Bavarians to absorb Prussian staff whose training and outlook are very different.

The forest schools and academies are now full to capacity, and it is the considered opinion of all senior forest officers with whom the matter was discussed that it will not be possible to absorb the out-turn of graduates into the State or the private forest services. The currency reform of June 1948 is likely, however, to affect a material weeding-out of these students, many of whom were dependent upon mark savings, the value of which was automatically decimated. While this currency reform bodes well for the rehabilitation of the country generally, it has inevitably created individual hardships.

On the labour side, again the position is not yet predictable. To what extent the reform of the currency may sway man-power from lower paid rural employment into the more lucrative industrial trades cannot yet be foreseen. It is likely that the acute housing shortage in all the larger towns, together with the better food situation in the rural areas, will both tend to keep men and women on the land. The opinion of most forest officials is that labour requirements for a big forest reconstruction programme will remain adequate for some years ahead, though the class of labour available and the *per capita* output of work remain very poor. An increase in available consumer goods following upon the stabilization of the new mark will doubtless improve this situation.

In the British Zone it is estimated that the following is the approximate personnel now directly employed in forest operations:

Forest officials	1,900
Office staffs	1,800
Permanent male forest workers	18,000
„ female „ „	500
Seasonal male „ „	9,000
„ female „ „	3,000
Total	34,200

This is less than one person per 100 acres, but it should be pointed out that the normal custom is for the buyers of timber to do nearly all the woodland conversion and haulage. Employment in the large commercial nurseries is excluded from these figures. The native timber trade absorbs approximately 1½ persons for every one directly engaged in forestry.

A substantial increase in the industrial forestry strength, including larger numbers of seasonally employed women, is visualized as an immediate necessity.

On the Allied side the Food, Agriculture, and Forestry Group at Bizonal U.S./U.K. Headquarters in Frankfurt has a staff of two American and one British qualified forest officers and a timber economist. In each of the *Länder* of the American Zone there is a trained forest officer seconded from the U.S. Forest Service. Forestry in each of the *Länder* of the British Zone is supervised by an officer unqualified in forestry but who has had some timber experience. In the French Zone, staffs of forest officers have been seconded from the *Département des Eaux et Forêts*. The North German Timber Control which previously functioned in the British Zone was disbanded on the formation of the Bizonal administration, but direct timber exploitation continued under the aegis of the British Timber Production Agency. This last organization, however, ceased to have any responsibility for the supervision of German forest policy or management and it has now practically closed down its operations. Forestry, so far as the Control Commission for Germany (British Element) is concerned, is thus represented by only one qualified forest officer.

The Land Reform legislation which will result in the breaking up of the larger private estates, if not very cautiously administered, may have disastrous results upon the future management of German forests. Whereas, on the average, even the larger private forest properties do not compare favourably with the production of the State forests, the really bad forest management is to be seen ubiquitously in the small farmer's woodland, and it would be lamentable if, under the guise of Land Reform, the large forests were to be broken up into small uneconomic parcels. The German State foresters, of course, argue that nationalization of the larger private forests will be in the best interests of sustained production, and this is the policy at present advocated in the case of certain forests in Schleswig-Holstein—the only *Land* in the British Zone where the Land Reform procedure is as yet being enforced. In any case, whether these woods are to be nationalized or not, it does seem most urgent to ensure that they shall not be broken down to

areas too small to be maintained as self-supporting normal forests. The Allied staffs will inevitably control to a considerable extent the operation of the Land Reform policy, and here the advice of qualified forest officers should be carefully considered.

Private forest owners, who control over a third of the area in the three Western Zones, and approximately half the area in the British Zone, are at present completely prevented from beginning any reconstruction work, through lack of money. Those owners who sold timber, compulsorily or otherwise, prior to the reform of the currency, and who may have reserved capital for replanting, have had their savings decimated. Under present conditions there is little likelihood that any of them will be able to undertake reafforestation. Though the Forest Departments of the *Länder* are optimistic that their replanting programmes will be fulfilled, the *Oberlandesforstmeisters* agree that nothing has yet been done to enable the private owners to undertake their portions. In Nord Rhein-Westfalen and in Niedersachsen the introduction of Forest Cultivation Laws are visualized, whereby owners will be compelled both to replant and to improve their standard of management. Financial assistance will be necessary: State loans, at a low rate of interest, which shall become repayable when the new crops reach productive age are advocated. Given such financial assistance there is little doubt that the majority of the *larger* landowners will co-operate with zeal, but the reformation of the small 'farmer's woods' calls aloud for a bold long-term policy and is fraught with many technical difficulties.

3. THE PROGRAMME.

The present project is based on a 7-year plan to reafforest 1,160,000 acres, being 372,000 acres in the U.S. Zone, 132,000 acres in the French Zone, and 656,000 acres in the British Zone, the last named being on a scale ranging from 67,000 acres in forest year 1948 up to a maximum of 112,000 acres in 1952. The distribution of the British Zone target is:

TABLE V

Forest year	*Reafforestation programme*			
	N. Rhein-Westfalen	*Nieder-sachsen*	*Schleswig-Holstein*	*Total*
	Thousand acres			
1948	30	27	10	67
1949	30	40	8	78
1950	37	48	10	95
1951	38	62	10	110
1952	35	65	12	112
1953	25	65	12	102
1954	12	65	15	92
Total	207	372	77	656

The largest programme lies in Land Niedersachsen, but here it is observed that it has been scaled up from a gradual beginning to reach its peak in 1952. This

plan is not unconnected with the finances of the *Land*, which does not carry such a high proportion of major industries as Nord Rhein and is, therefore, at present in a more precarious monetary position.

It may be estimated that some two-thirds of the forest restoration programme will have been completed at the end of the 7-year period if future fellings can be reduced to normality, though to an outsider the possibility of this last seems more than remote; viz.

Bare land estimated 1948	600,000 acres
Fellings 1948–54	262,000 „
	862,000 „
Reafforestation target 1948–54 . . .	656,000 „
Bare land 1955	206,000 „

Given reasonably good seed crops, the plant-supply position is adequately secured. Hitherto the huge commercial nurseries at Halstenbek in the south of Schleswig-Holstein had been the main source of supply to a large part of old Germany, and these nurseries are already getting back into full production. Covering a total of some 2,000 acres (the largest single firm in the group manages some 375 acres), this is undoubtedly the largest forest tree nursery area in the world. In addition there are fourteen other major commercial nurseries in the British Zone—seven each in Nord Rhein-Westfalen and in Niedersachsen. The State Forest Department, however, are anxious to ensure that all stocks required for private woodland owners shall be available, and with this objective, jointly with the desire to prevent inflationary price tendencies, they are opening up large numbers of small temporary *Kamps* in the State forests, especially in the plains where Scots pine (*Pinus sylvestris* L.) seedlings are the major requirement.

In the British Zone, and in most of the American Zone, the excessive fellings have occurred in areas where the Uniform System, with clear cutting and artificial regeneration, has been the old practice, so that the damage has been one of degree only and has not upset the system of silviculture. It is true that in the Harz Mountains abnormal clear fellings have resulted in moderately severe damage by wind-throw, and that there is some danger of upset to water flow-off. Of material erosion there is, however, little evidence. The growth of *Vaccinium* and other herbage has been generally rapid. Stump and root extraction on the slopes of the Harz has been prohibited.

In the Black Forest the clear fellings by the French have been comparatively small and generally the long-maintained systems of natural regeneration have not been grievously maladjusted. To an even lesser degree have the Spessart forests of Bavaria and Hesse been interfered with under American control.

4. SILVICULTURE.

Estimates obtained from the *Landesforstämter* of each of the three *Länder* in the British Zone give a good idea of the magnitude of the 7-year programme and the distribution of the forest types to be reafforested, viz.:

TABLE VI. *British Zone: 7-Year Programme*

1948–54	*Scots pine**		*Spruce,† Weymouth pine,‡ and Larch§*	*Hardwood*	*Total*
	Direct Sowing	*Planting*	*Planting*	*Planting*	
By area, per cent.	10	40	37	13	100
Thousand acres	65	265	241	85	656
Seed, thousand lb.	114	66	66	?	?
Plants, millions	0	2,120	697	340	3,157

* (*Pinus sylvestris* L.). † (*Picea abies* Karst.). ‡ (*Pinus strobus* L.).
§ (*Larix decidua* Mill.).

It is most noticeable everywhere that the cult of the pure forest has entirely lost favour. In Land Niedersachsen the silviculturists are less emphatic than elsewhere on the need to maintain a percentage of hardwoods with their spruce and pine: they express the desire to do so, but in practice they are adhering largely to pure conifer woods. There is a regrettable lack of liaison between one *Land* and another on technical developments, and of course an almost complete lack of knowledge amongst all except a few of the research specialists as to what is going on in other countries. For example, in the Black Forest work was being done in the afforestation of *Calluna–Vaccinium–Scirpus* heathland, planting in the bottom of deeply screefed furrows, with and without ameliorating nurse crops of broom (*Cytisus scoparius* Link.) and shrub lupins (*Lupinus*). Turf planting was unknown. Foresters dealing with difficult dry heathland on the Lüneburger Heide (Niedersachsen) had received no information upon the earlier work carried out on very similar heath at Senne (Nord Rhein-Westfalen). The formation under the Third Reich of a unified German Forest Service had had the advantage of pooling of technical information, while it still maintained in some degree a healthy decentralization under the provincial directorates. Pending the reformation of a German (or Western German) political administration the Forest Departments are now completely broken down to *Land* bodies. The German Director at Bizonal Headquarters in Frankfurt has no administrative control over the functions of the *Länder*.

Seed collection has become a highly specialized task and, particularly in the case of Scots pine (*Pinus sylvestris* L.), no uncertified seed is allowed to be collected, used, or sold. Collection is limited to registered stands and largely to selected individual trees in such stands. Training courses are run for seed collectors (seed monkeys), who learn to perform feats of incredible agility, equipped only with the simplest form of climbing iron and scorning the use of safety straps. Several new seed extraction stations have been opened and after the current season, which has been a good spruce (*Picea abies* Karst.) seed-year, it is anticipated that adequate supplies of all the major species will be assured. There is a demand for more American red oak (*Quercus* spp.), Douglas fir (*Pseudotsuga taxifolia* Brit.), and (mainly in Schleswig-Holstein) Japanese larch (*Larix leptolepis* Gord.) and Sitka spruce (*Picea sitchensis* Carr.) than has yet been available.

Hitherto importation of these species has been difficult, but the Bizonal Joint Import-Export Agency should facilitate international trading in future.

Nursery technique in many of the State forest nurseries is fairly poor, but the new *Kamps* for production of pine seedlings in the sandy heathland of the plains give generally good results. The normal practice on typical *Vaccinium–Pteridium* land, after grubbing out the stumps and first deep cultivation, is to give a moderate dressing of lime (1½ tons per acre), roll, harrow, and sow in drills spaced at 8 or 9 inches apart at the rate of 40 lb. of seed per acre. A normal yield of 1-year seedlings fit to plant is 13,000 per pound. In the Harz Mountains experiments to raise 2-year Norway Spruce (*Picea abies* Karst.) fit for planting, by sowing on a very strong mulch of spruce raw humus mixed with the native heavy soil, followed by copious watering until the seedlings are thoroughly established, compares more than favourably with many of the wasteland nurseries in Britain.

The old-established commercial nurseries at Halstenbek, mentioned above, have been in existence for a century or so, and there is evidence that for the past 30 years the standard treatment has been with farmyard dung, say, 24 tons per acre after every cropping, with alternating fodder crops, commonly of oats or rye, and with occasional light dressings of lime. It is considered important to avoid any trace of acidity in the soil! The normal farmyard dung is, of course, largely formed with a heather (*Calluna*) or *Vaccinium* bedding material and thus is comparatively free of weed-seeds. Fertility is certainly well maintained, and normal spruce stocks of 2+1 would be used according to British standards, though the Germans still prefer a larger 2+2 or 2+3 transplant. Hitherto nearly all conifers have been sown broadcast, but with present shortage of labour there is a strong swing-over to drill sowing, which has been found greatly to speed up weeding and cultivation. There is very little mechanization. Employment in these nurseries is stated at present to be just under 1 person per acre, on the average, though this is not considered to be quite adequate. About 75 per cent. of employees are women or girls.

One-half of the reafforestation programme in the British Zone (and probably this ratio is also approximately correct for the U.S. Zone) is to be with Scots pine (*Pinus sylvestris* L.) or mixtures in which Scots pine predominates. The normal practice, where pan is absent, is to screef strips about 18 inches wide at 4 ft. 3 in. centres, either by hand with mattocks or by ploughs, merely to remove the turf and raw humus. A light plough devised by Oberlandesforstmeister Stehle, with a simple stump-jumping device, is generally sought but is in short supply. It is pulled by tractor, ox, or even milch cow. There is a distinct preference for reafforestation in these screefed strips by direct sowing. The bottom of the screef is slightly cambered up to the centre to obviate rain-wash, and a thin drill of seed, at a rate of 1½ to 2½ lb. per acre, is sown on the crown of the camber, lightly covered with the native sandy soil. Owing to present shortage of seed, due partly to lack of trained seed collectors, all *Forstmeisters* have been greatly restricted in the amount of direct sowing they may do, as on the average this process consumes about five times as much seed per acre as planting. In Hesse, and, it is believed, in the whole of the Russian Zone, direct sowing is forbidden (though it is certainly

still carried out in Hesse). Results generally have been excellent, and even the lightest density of sowing seen had yielded a very thick crop of strong seedlings. Trials with as little as ½ lb. of seed per acre have been made with adequate results during the past moist season. If failures are of material extent they are made good by lifting in dense patches and ball-planting in the blanks, at the first or second year.

Where reafforestation is done by planting, the normal practice is to use 1-year seedlings vertical-notched at a spacing not exceeding 14 inches apart in the 4 ft. 3 in. strips, giving a density of 8,000 to 10,000 seedlings per acre. Excepting in Land Niedersachsen it is a general practice to plant hardwoods in addition at 6- to 9-foot spacing in every row or every alternate row. American red oak (*Quercus* spp.) is perhaps the most frequently used, but maple (*Acer*), birch (*Betula*), one of the alders (*Alnus*), or even rowan (*Sorbus aucuparia* L.), are acceptable. On better soil types, where a more loamy consistency occurs, some larch, either as seed mixed with the pine seed or as transplants where pine seedlings are planted, may be added. In Niedersachsen, also, it is a very common practice to bring in about 15 per cent. of Norway spruce, the value of which is almost solely to maintain a ground cover for the benefit of wild pig and deer, as it invariably remains heavily suppressed by the pine and seldom attains an economic position in the crop.

Where pan occurs, as, for example, on the 30,000-acre battle-training area of Senne in Nord Rhein-Westfalen, very thorough ploughing is done in an endeavour not only to break the pan but to bring the whole of it up to the surface. Previously to this area being taken back for reafforestation it comprised level or very gently rolling *Calluna* moorland, with a strongly defined hard pan at 10–20 inches depth beneath a heavily leached acid sandy podsol. Here and there occurred areas of erstwhile 'farmer's forest' of pine, completely stunted and flat-topped at a height of 40–50 feet, and averaging 90 years old. These woods clearly showed that the pan was impenetrable to the tree roots. Reafforestation began on a big scale in 1940, and the subsequent experimental work covers some 1,250 acres. The standard practice, which appears well justified by the results achieved, is now to give a complete ploughing to bring the whole of the pan to the surface. Steam tackle is used in the absence of crawler tractors. This is followed by a dressing of 1½ tons per acre of marl or limestone quarry waste. As the full ploughing creates a temporarily desert condition accompanied by some degree of sand blast, it has been found necessary to use 2-year pine seedlings, but a regular mixture of 15 per cent. of alder (*Alnus glutinosa*, Gaertn.) grey alder (*Alnus incana* Willd.), red oak, or birch is invariably added. Partial ploughing, strip hand-digging to break the pan beneath the planting lines, and planting without the lime dressing have all given inferior results, both in the survival of the hardwoods and in the rate of growth of the main crop.

At Führberg on the Lüneburger Heide, similar complete ploughing is conducted, followed by careful harrowing, but as there is no pan here and the previous pine crop had been of good quality, the expense of this work was not really justified. In fact the only reason seemed to be to regain a level surface after the old roots had been pulled or blasted out for the provision of fuelwood.

Little work has been done on the German plains in an endeavour to secure natural regeneration. Much of the old pine crop was of poor form and of very mixed or unknown origin, and it is desired to bring in better races. On the other hand, it seems evident that the poor quality may in some forests be due more to bad silviculture than bad types. At Darmstadt (Hesse), where bare shifting sand was afforested within the past 120 years and less, the introduction of a beech under-story after the first real thinning is already creating an excellent forest soil condition. At the Gartower (Niedersachsen) private forest, however, very good regeneration is secured on a novel system. The violent storm which wrought untold havoc all over Germany in November 1940 did not spare Gartower, but Forstmeister Junach noticed excellent re-seeding on the soil exposed by the torn-out pine roots. Instead of making seeding fellings he now winches his trees down and the local peasants pay 9 pfennigs a tree for being allowed to do the work and to remove the roots and brushwood. He thus has no felling costs, no stumps wherein beetle or weevil might breed, and he gets his seeding patches naturally cultivated in exactly the right distribution.

Reafforestation in the big spruce forests of the Harz Mountains has not yet commenced on any important scale, on account of shortage of plants. A very good seed-year has now occurred. It was surprising to learn that no real plan for the formation of mixed forest had yet been considered. The prevalence of heart rot, the amount of storm damage, the high incidence of *Ips typographus* L. and the soil deterioration under the old pure spruce forest all admittedly pointed to the need for improved silviculture. The lower slopes of the Harz were originally beech (*Fagus sylvatica* L.) forest of good quality.

In the spruce-silver fir (*Abies alba* Mill.) areas of the Black Forest great stress is now laid on the necessity to ensure the introduction of hardwoods naturally or artificially. In Forstamt Reichenbach, where natural regeneration according to Wagner's *Blendersaumschlag* method had been practised on the southern slopes, the over-preponderance of spruce seeding was being countered by artificial planting with native oak (*Quercus robur* L.), red oak, and silver fir. Elsewhere groups of beech (*Fagus sylvatica* L.) were being planted in advance of the main seeding fellings.

At the private forest of Die Haard, situated in Nord Rhein close to the industrial area of Hamm, Recklinghausen, Gelsenkirchen, &c., the very poor growth of pine was partly attributed, though admittedly not with complete conviction, to atmospheric pollution. This had originally been a communal forest of hardwoods, yew (*Taxus baccata* L.), and juniper (*Juniperus communis* L.), but due to unrestricted cutting it had deteriorated to open heathland. About 1800 it was acquired by the Duke of Arnsberg, who began to replant with pine. The big storm of November 1940 blew down 1·8 million cu. ft., and between 1942 and 1948 as a result of Allied bombing, fighting, war-time and post-war (N.G.T.C.) fellings, half the forest was devastated. Private Forstmeister Lincke began a systematic programme for the conversion of the worst pine back to hardwoods about 18 years ago by reducing the pine (average age 40–60 years) to a 0·4 stocking, retaining only the best [*sic*] trees. Two-metre strips, with one metre

between, were hand cultivated, the raw humus and *Vaccinium* turf being banked on to the metre strips. The cultivations were sown at the rate of 350 lb. per acre with red oak and beech, either mixed or in alternating patches. Three years later the turf banks were planted with a small number of Douglas fir, Japanese larch (*Larix leptolepis* Gord.), or Lawson cypress (*Cupressus lawsoniana* Murray), but these have nearly all become completely suppressed. The regular and comparative growth of the red oak and the beech has been excellent, however, with the former maintaining just the right one-fifth to one-quarter ascendancy over the beech. Had the sowing density been halved, the results might have been equally encouraging. Selective cuttings begin at 15 years and will be repeated triennially. Needless to say, in this district there is a steady sale for pea and beansticks, though all the beech rods go to a local factory for manufacture into 'horn' and commoner buttons. Red oak of larger sizes is readily saleable for pitwood. No post-war continuation of this reafforestation programme has yet been possible owing to the financial straits of the colliery company who now own the forest.

The Graf von Westfalen at Furstenberg in the Sauerland is also converting parts of his spruce forest, where severe wind damage had occurred, to hardwoods. His Forstmeister Roosen has devised a successful system of reafforestation in combination with food production. He sows acorns, beech, birch, and maple in drills at metre spacing, after rough soil cultivation, and then broadcasts with oats and Johannes rye (a biennial crop). The oats can be harvested by hand in a more or less normal manner. In the second year the rye is harvested by sickle, leaving a very tall stubble, by which time the tree seedlings are well established and the ground is fairly weed-free. He claims that the revenue from the two food crops is slightly in excess of the cost of the whole reafforestation operation.

5. THINNING.

The extreme density of pine planting methods—a system which has been in operation for many years—naturally creates a thinning problem quite different from any we normally meet with in Great Britain, but it is a problem which the Germans do not appear to have tackled systematically. Oberlandesforstmeister Stehle demonstrated that the first selective thinning *should* take place within 5 to 10 years after formation, by a heavy wolfing. In the sample shown it was less than 50 per cent. of the suppressed and often entirely weakling trees which remained. In practice, however, this very early selective cutting is *not* carried out. In crops up to the age of 25 years and more one sees everywhere these dense thickets of lanky self-suppressed stagnating forest, with small weak crowns and an impenetrable mass of thin dead branches below. The first two thinnings are reasonably careful and gradual: it is only the second one which yields substantial quantities of saleable produce. Between 30 and 45 years the forest is heavily opened out. The principle is obviously to secure quick suppression of branches and clean boles. In practice the closeness of initial planting and the difficulty of getting into the thickets for the first thinnings are probably more costly than our method of wider spacing and brashing. The weakening of the whole crop during a decade or two of extreme over-density certainly militates against quick diameter

increment in the second half of the rotation, and it is in large diameter softwoods that Germany has been deficient for the past generation and is grievously lacking at the present time of distress.

6. PROTECTION.

The first opinion of German foresters, if asked what has caused the greatest damage to their forests within recent years, is an unequivocal condemnation of the North German Timber Control. If pressed, however, they may *almost* admit that the damage caused by deer in the spruce forests has been even greater. The one has been stopped: the other has not. Directly after the war no German foresters, of course, were permitted to possess rifles. This regulation has already been eased and will doubtless be progressively relaxed. Every German forester is, however, primarily a huntsman, and until there is a change in the feeling towards deer and their relationship to the economy of German forestry, it will be forestry that suffers.

Ips typographus L. is at present abnormally prevalent and doing severe damage in the spruce forests throughout Germany. Its increase can certainly be attributed in part to large-scale clear fellings, and to the large quantities of logs and pulpwood left lying in the forests during and after 1944–5, when haulage operations came to a standstill. Severe outbreaks are reported from Bavarian forests where little abnormal exploitation has taken place. It is stated that mixed spruce-beech forest in Bavaria is almost free of *Ips*, while pure spruce near by is heavily attacked. As a preventive measure against further increases, all spruce is now compulsorily peeled immediately after felling, but stumps—often cut very high by unskilled fellers—remain untreated.

Dendrolinus pini L. has now been epidemic in the neighbourhood of Forst Gartower (Niedersachsen) for three successive years. It is estimated that an area of 375 acres has been completely stripped during the 1948 season, which is rather less than occurred in the previous year. Grease banding has not been fully effective, as the vast numbers of caterpillars present have soon pressed over and formed live bridges across the bands. The boundary between the Russian and British Zones takes an ill-defined line through Gartower Forest, but the conditions on the eastern side are not known. It is stated that *Dendrolinus* has never before become epidemic in western Germany, though it is one of the major plagues farther east.

The large-scale replantings in the pine forests of the plains will bring in their wake a new problem in fire protection, where, hitherto, the forests have been reasonably broken up in varying age classes. It is the intention in the largest areas to break up the young crops with cultivated strips up to 100 yards in width. Wherever possible these belts will be handed over to the Agricultural Department for maintaining under fodder-crops for 20–30 years. They will not be permanently excluded from the forest but will be planted as soon as the main blocks have been thoroughly thinned and become reasonably safe from ground or thicket fire hazard. In the most dangerous territories of large even-aged young plantations it is visualized that as much as a quarter of the area may thus be disforested

for a generation or more. Wind damage is feared in all the German forests after the immense havoc of the storm in November 1940 (e.g. 8 million cu. ft. at Kleve, Düsseldorf, on 15,900 acres; 1·8 million cu. ft. on 9,500 acres at Die Haard; 3 million cu. ft. on 16,250 acres at Lüss, Lüneburg, to quote typical examples right across from west to east of the British Zone), and it is for this reason, as much as for any other silvicultural benefit, that mixed woods are now considered to be necessary.

SUMMARY.

Western Germany has suffered from forest over-exploitation since Nazi times and this was accentuated during the war years and the post-war period. Much propaganda has been disseminated to the effect that post-war export of timber to Allied countries has been a major disaster. Facts are that the proportion of felling for export has been comparatively small. Control of internal timber consumption, always inadequate, is now being relaxed further, while exports to the Allies are to be greatly reduced.

Western Germany's reafforestation programme of 1,160,000 acres is being undertaken on a 7-year plan, and provided that legislation can be passed and implemented to help private forest owners, there seems every prospect that the objective will be attained. There is an urgent need to improve the standard of management of the small 'farmer's forest', which has never been tackled by Germany hitherto. The cult of the pure forest in Germany is dead. All foresters are in agreement that a reversion to sound mixtures with hardwoods is necessary, but this policy is not being converted into action in Land Niedersachsen so much as it is elsewhere.

Over-density in the younger pine woods has led to grave loss in diameter increment. The present and future shortage in Germany is in the larger-sized logs. The past and present silviculture of their pine forests is perpetuating this shortage.

Deer damage in the German spruce forests remains enormous. A different outlook on the economic position of forest hunting is necessary. *Ips typographus* L. and *Dendrolinus pini* L. have become serious pests. Fire protection in the large blocks of new even-aged plantations will include wide belts of agricultural food crops.

Protection against wind damage is given serious consideration, and here again the formation of mixed woods is considered to be an essential feature.

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FOMES ANNOSUS FR. ON PINES IN EAST ANGLIA

By J. RISHBETH

(*Botany School, University of Cambridge*)

INTRODUCTION.

A ROOT disease of pines has recently caused serious damage in some plantations established by the Forestry Commission in East Anglia. Macdonald [1939 (4)] first drew attention to these outbreaks when they were confined to young trees planted on former woodland sites. Shortly after this there was a more serious development of the disease, which killed numerous 20-year-old pines, chiefly on former arable land. In September 1945 Professor Brooks suggested that I should investigate the biology of *Fomes annosus* Fr., which was apparently the causal fungus, with particular reference to the killing of pines. This paper summarizes the results so far obtained and is especially concerned with those aspects of the problem which have a bearing on forestry practice.

The disease has developed in two main areas, the first of which comprises the Thetford and Swaffham forests lying for the most part in the area known as Breckland. The second area, comprising the Rendlesham and Tunstall forests, lies a few miles from the coast of east Suffolk. The characteristics of these areas will be briefly described, since they have a bearing on the incidence of disease. In both areas the rainfall is low, the average annual figure for the last 10 years being 21 inches. In Breckland the soils are derived from a chalky glacial drift and interglacial sands, the underlying formation being chalk. The soils are uniformly sandy, but show a considerable variation chemically: where the chalk is near the surface the calcium carbonate content and pH value are high, but in other areas the base status and pH value are low, and well-developed podsols may be present. The natural vegetation is largely grassland with societies of bracken and sand sedge, but considerable stretches of heath are dominated by *Calluna*. Much derelict arable land is also present, and its soil is nearly always alkaline. In east Suffolk the soils are derived from a sandy or gravelly drift, beneath which is Norwich Crag. With the exception of land formerly cultivated, the soils are very acid, and *Calluna* is dominant over most of the area.

Fomes annosus Fr. is well known as an agent of root and butt rot in conifers over a wide range of localities in the northern hemisphere. The killing of young conifers by the fungus is also widespread. Devastating attacks are recorded from 20–30-year-old pine plantations in south-west Sweden [Rennerfelt, 1947 (6)]. Serious losses of pines have been reported from France, Belgium, and Germany. The killing of 200-year-old pines in a dry, sandy region of California has been ascribed to the fungus [Wagener and Cave, 1946 (7)]. One of the few records of a similar nature from the British Isles is by Anderson [1924 (1)], who found groups of dead pines in Northumberland and Lanarkshire. Although the survey made by

Peace [1938 (5)] shows that *F. annosus* Fr. is widespread as an agent of butt rot, it is clear that the outbreak in East Anglia is the first of its kind on any considerable scale in this country.

Previous investigations on the parasitic activities of *F. annosus* Fr. have been concerned almost entirely with the problem of butt rot. Although this disease is likely to have something in common with the killing of trees, it cannot be assumed that earlier work is a safe guide to the state of affairs in East Anglia. It is known that the fungus lives in stumps as an agent of decay, but the mode of infection has not been clearly elucidated. There have been references, for example, to infection by a saprophytic growth through the litter, by spores brushed off on to roots by rodents, and by the contact of living roots with others already infected. Again, it has often been stated that the roots are predisposed to attack by various physical or chemical agencies and that infection will only take place when the roots are weakened or actually dead. It is not surprising, in view of its widespread distribution, that disease caused by *F. annosus* Fr. has been associated with an exceptional number of site factors. It is generally agreed, however, that severe attacks are frequently encountered in plantations on former arable land.

THE OUTBREAKS OF DISEASE.

In East Anglia plantations have been established on former woodland, arable, and heath (this last including, for convenience, various types of grassland and *Calluna* heath). Root disease has killed young trees on former woodland sites right from the beginning of planting. Areas replanted after fires also show disease at an early stage. By contrast, disease has only appeared on former arable and heath sites following the felling of trees. In such sites there are many instances of trees dying at the edge of a felled woodland strip or along the border of rides or racks. The most devastating attacks, however, have all followed thinning in young plantations; in some the 'wolf' trees were taken out and in others the thinning was experimental. It is characteristic of the disease that the trees die in groups, often circular, which are sometimes as much as 30 yards across.

F. annosus Fr. was repeatedly isolated from the roots of affected trees and was found in the earliest stages of attack at the junction of healthy and diseased tissues. This confirms the observation made by Day [1948 (2)]. With the exception of *Armillaria mellea* (Vahl) Fr., which was present in some trees on former hardwood sites, no other pathogen was isolated. In addition, as typical symptoms of disease were produced when living roots were experimentally infected with *F. annosus* Fr., there can be little doubt that this fungus is the causal parasite.

F. annosus Fr. is present in stumps in every site where disease has developed. Usually the stumps are of conifers, but birch and, more rarely, oak also contain it. The fungus is occasionally found in the stumps of gorse (*Ulex europaeus* L.) cut out during cleaning. Investigation of early stages of infection showed that in every instance the fungus had invaded the living root at a point where it touched another one already infected. The first trees to be killed are always infected from stump roots, but such trees can in turn transmit the disease to adjacent ones. Stump roots never infect living roots unless they are in intimate contact with

them, but this is not an important limitation to the spread of disease, since root contacts between living trees are frequent in plantations from about the eighth year onwards.

It is notable that discoloration and other symptoms of the crown appear only relatively late, when the root system is heavily infected. *Myelophilus piniperda* L. often invades the trunk while the fungus is still confined to a few main roots, and this invasion may well hasten the death of the tree. The beetle population in a typical group of diseased trees must be enormous.

THE STATUS OF *FOMES ANNOSUS* FR.

If *F. annosus* can live saprophytically in litter as well as in stumps, the potential source of infection of living trees is very great, and in some circumstances invasion through the mycorrhizal roots might take place. In view of the conflicting opinions on this point appearing in the literature, it was thought desirable to obtain further evidence. The ability of the fungus to grow from an inoculum on to soil, litter, and other natural substrates was therefore tested. It was found that *F. annosus* would grow readily if these materials were previously sterilized by autoclaving, but that growth was variable if they were unsterilized. On unsterilized litter and humus, for example, little or no growth took place. The fungus grew better on soil from a depth of a foot, but even so, growth was feeble. It is difficult to imagine roots being infected by mycelium present in the soil, since other work on root-disease fungi has often shown that a substantial food base is required in order to achieve infection. Experiments also indicated that living roots are very unlikely to be infected by the spores of *F. annosus*.

Field observations threw some light on this problem. The mycelium of *F. annosus* was never seen growing into the soil, even from heavily infected roots, and transfer by root contact was very prevalent if not universal. The fungus was never found on the root systems of pines killed by suppression. Had it been present in the soil or litter, it would probably have invaded at least a proportion of such trees, whose resistance just before death is presumably low. Lastly, *F. annosus* was never found on the root systems of pines unless stumps were present in the immediate vicinity. As roots often die during the normal growth of these trees, opportunities for colonization by a fungus such as *F. annosus* would occur, presumably, if it lived freely in the soil. Its distribution on roots is so limited that the fungus is almost certainly not present in the soil. It follows that *F. annosus* is probably absent from plantations on former heath or arable until trees are cut out.

The ability of *F. annosus* to grow from inocula on to the surface of unsterilized roots depended on the site from which they were taken. Broadly speaking, growth was vigorous on roots from most alkaline soils but was very limited on those from the acid soils of former woodland and *Calluna* heath. This is interesting, since the disease was far more prevalent on the former soils than on the latter.

In most of the instances already mentioned, the failure of *F. annosus* to grow on unsterilized materials was associated with its overgrowth by a green mould, *Trichoderma viride* Pers. ex Fr. Experiments with *T. viride* revealed that many

strains could kill *F. annosus* and often replace it in wood. Such replacement was slower in wood recently colonized by *F. annosus* than in wood well rotted by the fungus, and was particularly slow in resinous wood. The rate of replacement by *T. viride* also varied with temperature: at 15° C. and above it was relatively fast, but at 5° C. it was very slow or did not take place. It is likely, therefore, that this replacement of *F. annosus*, which was often observed in stumps, takes place at varying rates throughout the year and may cease during the winter. Some strains of *T. viride* are known to produce powerful toxins, but toxin production was relatively feeble in the strains isolated from East Anglian soils. It is probable that when hyphae of *T. viride* and *F. annosus* are in contact, the secretion of a relatively small amount of toxin is sufficient to inactivate the latter. Some species of *Penicillium* were also found to be antagonistic to *F. annosus*, as were the wood-rotting basidiomycetes *Peniophora gigantea* Fr. and *Hypholoma fasciculare* Huds., which are very common in pine stumps. There seems good reason to believe, therefore, that *F. annosus* fails to grow on many natural substrates because it is unable to compete with certain other fungi.

SPORE PRODUCTION AND THE INFECTION OF STUMPS.

As *F. annosus* is unlikely to enter stumps from the soil, some other method of colonization must exist. This raises the interesting problem of whether stumps are infected by wind-borne spores. The idea was suggested in 1921 by Petch, who studied root-disease fungi in rubber plantations, but it has never been confirmed by experiment. It is now more generally believed that, in tropical plantations at least, root-disease fungi are already present on the tree roots and occupy the stumps after felling. If it is true, as already suggested, that *F. annosus* is initially absent from plantations on previous heath and arable, an excellent opportunity to determine whether the fungus is established by spores should be provided by stumps left after the first thinning.

It was found that the basidiospores of *F. annosus* would germinate on freshly cut, unsterilized wood surfaces, provided that the relative humidity was greater than 92 per cent. Furthermore, it was possible regularly to obtain infection of small pine stumps in the plantations by spraying the cut surfaces with a suspension of basidiospores immediately after felling. The fungus produces sporophores at all times of the year on stumps and dying trees, provided that the humidity is sufficiently high. Sporophores are also occasionally found in the litter attached to small dead roots; and in summer they are often present in underground cavities or on stumps covered by a pile of branches, although absent in more exposed situations. Spore production is continuous unless arrested by severe frost, and the spores, being very minute, are probably carried considerable distances by wind. It appears then that basidiospores are not only capable of infecting stumps but are produced in sufficient abundance to do so over wide areas.

There are two main reasons for believing that this is the most important means of natural infection. The first is that *F. annosus* was found in stumps where the wood was scarcely discoloured and had not been attacked by boring insects; in one instance it was found within 7 weeks of felling. In the early stages of infection

the fungus was present in a thin wedge of wood extending downwards from the cut surface to a region just below soil level; it was not present in the outer wood or bark. In the later stages *F. annosus* colonized the wood extensively and regularly grew on to the inner surface of the bark. Moreover, the fungus could always be found growing along the lateral roots in a direction away from the stump, which again indicated that the stump had been infected first. These observations are consistent with an infection of the cut surface by air-borne spores. Secondly, it was found possible to reduce the incidence of stump infection by *F. annosus* by creosoting the cut surfaces immediately after felling. This method would hardly have been effective if the bulk of infection came from the soil or roots. The fact that creosoting was not completely effective was probably due to the cracking of the wood as the stump dried out.

One interesting experiment, suggested by Professor Brooks, was the thinning of several plantations at monthly intervals during 1946, each month's thinning being restricted to a definite plot. The object was to discover whether the extent to which *F. annosus* colonized stumps varied throughout the year. It was found that, on the average, over 30 per cent. of the stumps of trees felled from January to April were infected by the fungus, but that the proportion dropped to about 10 per cent. in May to July. The amount of infection increased later in the summer, but fell in November and December. It is difficult to explain these results, but it is possible that humidity and the number of spores of *F. annosus* in the air were factors determining the amount of infection. There is reason to believe that *F. annosus* must become established in stumps within a few weeks of felling and that colonization of the cut surface after a longer interval is prevented by competing fungi.

It is worth stressing that these conclusions relating to the infection of stumps by spores are valid only for sites where no stumps have previously existed. It will be shown later that, for such sites, an alternative means of infection is possible.

As stumps containing *F. annosus* cause infection, it is important to have information about the growth of the fungus in them and to know how long it can survive. The average growth rate in stump roots was found to be about a metre per year, so that, with a planting distance of 1·4 m., *F. annosus* growing on such roots can closely approach adjacent trees within a year. The full occupation of the root system of stumps must take several years. Other fungi compete with *F. annosus* in stumps at an early stage. When small stumps were inoculated with *F. annosus*, it was sometimes replaced by *Trichoderma viride* Pers. ex Fr. or by *Peniophora gigantea* Fr. within a few months. Competition between fungi is in fact so widespread in stumps that the irregular distribution of *F. annosus* is hardly surprising. It is interesting to note that *F. annosus* is more frequent in large stumps than in small ones of the same age, possibly because competition is less intense in a larger volume of wood.

As long as *F. annosus* remains in stumps, the living roots of adjacent trees may become infected. The fungus is often found in large stumps 15 years after felling and is occasionally still present after 30 years. *F. annosus* is replaced in stumps by

other fungi more slowly in alkaline soils than in most acid ones. Ten years after felling the 'wolf' trees, for instance, the length of stump laterals still containing *F. annosus* in a plantation on former arable was nearly six times as great as that in a plantation on former *Calluna* heath. This difference was almost certainly due to the type of microflora present in the respective soils.

THE PARASITIC PHASE.

As already mentioned, *F. annosus* first appears on living roots at the point of contact with roots already infected by the fungus. At the time of invasion the living roots seem outwardly healthy and their internal structure is also normal. No clear instance was found where invasion had been preceded by the formation of abnormal zones in the root. *Hylastes ater* Payk. occasionally makes tunnels in living roots around stumps, but there is no indication that such roots are more likely to be invaded by *F. annosus* than normal ones. Similarly, there is no evidence that dead roots afford a means of entry for the fungus. This is understandable, because dead roots are colonized by many different fungi and it is probable that *F. annosus* cannot compete successfully with more than a few of these.

F. annosus is apparently able to attack any part of the root surface. In small roots, up to about 0·3 cm. in diameter, the fungus often invades the wood soon after infection takes place, but in larger roots it usually colonizes the bark to a considerable extent before invading the wood. During this stage the bark is often split by the production of resin, and the fungus mycelium can be seen in thin sheets between the cork scales. In alkaline soils *F. annosus* often grows extensively along the cork scales on the root surface. In this way the fungus kills small root branches and sometimes invades the wood well in advance of the region of main penetration. In many acid soils, owing to the more intense competition of other fungi, no such superficial growth is possible, and *F. annosus* encounters the continuous resistance of living tissues. There is also evidence that fewer infections take place around stumps on many acid sites than on alkaline ones.

The roots resist infection of the living tissues by resin production and by active cell division. The vigour of this response is greater in large roots than in small ones, and also varies with the site. Roots in many acid soils resist infection vigorously, but in alkaline soils the response varies and may be almost lacking. After a variable period, gaps caused by the disease cease to enlarge, and this is probably brought about by an increased resistance of the roots to the fungus. For any given site the stage at which the disease ceases to advance is independent of the duration of the outbreak but is related to the age of the trees. The rate of spread of the fungus on the root systems is from 0·5 to 0·8 m. per year in alkaline soils, but only about 0·3 m. per year in many acid ones, and stability is achieved much later in the former soils than in the latter. In some arable sites about 20 trees have been killed around each infected 'wolf' stump. Although in any one outbreak the disease is eventually checked, it is unlikely that plantations on alkaline soils acquire complete immunity from further attacks. With further heavy thinning, for instance, the balance may again be shifted in favour of the fungus, and more trees may be killed.

At the edge of typical disease gaps it is common to find pines which have resisted the invasion of *F. annosus* in one or more lateral roots. The replacement of *F. annosus* by other fungi in the dead portions of such roots follows a course similar to that found in stumps. In most acid soils replacement is rapid, but in alkaline soils the fungus often remains for a long period, rotting the roots which it has killed. Since such partially infected roots are known to exist at the time of felling, it is likely that *F. annosus* can enter the stumps through them. This possibility is important in connexion with the first thinning of plantations on those former woodland sites where infected stumps and diseased trees are already present. It is also important in the thinning of plantations on former arable or heath sites where an earlier removal of trees by thinning or rack-cutting has led to a similar condition. In these instances, *F. annosus* might enter stumps through partially infected roots as well as by air-borne spores. This mode of infection is, however, more likely to occur in alkaline soils than in acid ones.

SOME FACTORS AFFECTING THE SEVERITY OF DISEASE.

It has been suggested that the outbreaks are associated with a series of unfavourable seasons. The investigation of former woodland sites shows that in many places trees must have been dying from about 1930 up to the present time. Similarly, in the more serious outbreaks which have followed thinning, trees have died every year since 1940. As there was considerable seasonal variation over these periods, it seems unlikely that unfavourable seasons are a decisive factor.

Repeated reference has been made to the contrast between alkaline sites and many acid ones. Striking differences in the incidence of disease are often found in adjacent sites where the chemical and biological conditions of the soil are very different but where the physical ones are similar. On former woodland sites, severity can roughly be assessed by counting the number of trees killed by the fungus. On such sites an average of 16 per cent. of the trees have been killed where the soil is alkaline, but only 4 per cent. have been killed where it is acid (pH 4·0–6·0). It is difficult to estimate the severity of disease on former arable or heath sites by this method, because the number of stumps left after thinning is very variable. It is found, however, that more trees die around infected stumps in alkaline soils than in acid ones, and another indication of severity is the faster rate of spread of *F. annosus* on root systems in alkaline soils, which has already been mentioned.

Another interesting correlation is found with the amount of decomposed organic matter at the soil surface. All former arable sites are deficient in surface organic matter, as are many former woodland sites which were extensively burnt before replanting. When the two factors are considered together, it is found that former woodland sites have 19 per cent. dead trees where the pH value is high and the surface organic matter low, and only 2 per cent. where these values are reversed. The thick layer of surface organic matter present in some plantations remains moist even during exceptional drought, and, therefore, because the area has a low rainfall and a very permeable soil, trees in such plantations may well be more

vigorous. In other sites, during drought, the soil dries out to a moisture content of less than 5 per cent. from the surface down to a depth of several feet.

Tree nutrition may well vary on the different sites and may affect the resistance to disease, but this aspect of the problem has not been investigated. The soil microflora varies greatly from site to site, and the fungus *Trichoderma viride* Pers. ex Fr., which is antagonistic to *F. annosus*, is far more abundant in acid soils than in alkaline ones. The importance of this biological factor cannot be overestimated. It influences the rate of replacement of *F. annosus* by other fungi in stumps and the number of infections taking place on living roots around stumps containing the parasite. It also determines the extent to which *F. annosus* grows on the surface of such infected roots.

It is difficult to state precisely why the outbreaks are so severe in East Anglia as compared with other parts of Britain. The killing of conifers, as distinct from butt rot, elsewhere in the world appears to be prevalent where the rainfall is low or there is a dry season. This condition is fulfilled in East Anglia and in addition the plantations there are on very permeable soil. It is possible that periods of water shortage lower the resistance of trees to disease. Further, many East Anglian soils are deficient in fungi such as *Trichoderma viride* Pers. ex Fr., which are antagonistic to *F. annosus*. This condition arises naturally where the soils are alkaline and also tends to arise as a result of former cultivation. The general prevalence of root disease on former arable sites, which is often quoted in the literature, may well be associated with this scarcity of fungi hostile to *F. annosus*.

PRACTICAL CONSIDERATIONS.

The timing of the more serious outbreaks is clearly associated with the first thinnings. Early stages of many further outbreaks can be found in plantations which have been thinned since 1942. Early felling of 'wolf' trees on alkaline sites is dangerous, for the size of the 'wolf' stumps and the state of the surrounding young trees favour severe attacks by *F. annosus*. The removal of trees for any other reason, at an early stage, may similarly lead to disease. Extensive burning on former woodland sites, although apparently an economical preparation for replanting, destroys the surface organic matter and thereby probably increases the incidence of root disease in the following crop.

Because *F. annosus* is replaced in stumps by other fungi relatively slowly, a short delay in replanting former woodland sites offers no solution. Control measures are, in fact, almost impossible once the fungus is below ground. The limitation of thinning to a certain time of year, such as early summer, might reduce the disease but would not prevent it. Treatment of the stump surface immediately after felling, for example, by creosoting or painting, appears to be the most hopeful solution, and a large-scale experiment to test various methods is in progress. Even if such a treatment prevents infections by air-borne spores, it would be, probably, only partially successful in sites where infected stumps or diseased trees already exist. From what has been said it is clear that the East Anglian plantations are not homogeneous, so that control, however desirable in some sites, might not be necessary in others.

It is too early to state what bearing these findings have on the problem of butt rot by *F. annosus*, but it is interesting to note that the association of butt rot with earlier thinning has already been recorded [Hepting and Downs, 1944 (3)]. As the colonization of stumps by air-borne spores may well precede such outbreaks, some measure of control might be achieved by the means already indicated.

SUMMARY.

1. *Fomes annosus* Fr. has recently caused serious damage to pines in some East Anglian plantations. The areas affected have a low rainfall and sandy soils, which show a considerable variation chemically.

2. Trees are often killed on former woodland sites soon after replanting, but disease only appears on former arable or heath sites following the felling of trees. The trees characteristically die in groups.

3. The fungus is present in stumps in every site where disease has developed. Infection takes place by the contact of living roots with roots already infected. The first trees to be killed are infected from stump roots, but such trees can transmit the disease to adjacent ones.

4. *F. annosus* Fr. does not live freely in the soil but is confined to woody tissues, probably because it is unable to compete with certain other fungi, of which *Trichoderma viride* Pers. ex Fr. is an example.

5. Air-borne spores of *F. annosus* Fr. can colonize freshly exposed stump surfaces, and therefore operations such as thinning enable the fungus to become established in plantations where it was formerly absent.

6. *F. annosus* Fr. takes several years to occupy the root system of stumps and is often still present 15 years after felling. It is eventually replaced by other fungi.

7. The living roots are healthy at the time of infection. The progress of infection varies with the size of root and with the type of soil. The resistance of pines to *F. annosus* Fr. increases with age.

8. The disease is more severe in alkaline soils than in acid ones, and also tends to be severe where soils are deficient in surface organic matter. Many soils, especially the alkaline ones, are deficient in fungi antagonistic to *F. annosus* Fr., and hence the type of soil microflora is a factor of great importance.

9. Some practical implications are considered, and it is suggested that a measure of control might be obtained by treating stump surfaces immediately after felling.

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FIG. 1. Scots pine (*P. sylvestris* L.) attacked by *Fomes annosus* Fr.

FIG. 2. Corsican pine (*P. nigra* var. *calabrica* Schneid.) attacked by *Fomes annosus* Fr.

FIG. 3. Twenty-one-year old Scots pine severely attacked by *Fomes annosus* Fr., 7 years after a heavy thinning.

FIG. 4. Adjacent plot of Scots pine, of same age as in Fig. 3, not thinned and not attacked by *Fomes annosus* Fr.

PLATE VII

FIG. 5. Young Scots pine (*P. sylvestris* L.) killed by *Fomes annosus* Fr. (Arrows ↑ show where its roots are in contact with infected stump roots.)

FIG. 6. Sporophore of *Fomes annosus* Fr. on a still living Corsican pine (*P. nigra* var. *calabrica* Schneid.).

PLATE VIII

Forester Training School, Lynford Hall, was particularly valuable. Grateful acknowledgement is made to the Director of the Forest Products Research Laboratory, Princes Risborough, for identifying cultures of basidiomycetes, and to Mr. P. M. B. Walker for taking the photographs.

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DESCRIPTION OF PLATES.

Fig. 1. 7-year-old Scots pine (*Pinus sylvestris* L.) on a former woodland site. One tree (foreground) near an old infected stump is already dead and another behind is discoloured.

Fig. 2. 20-year-old Corsican pines (*Pinus nigra* var. *calabrica* Schneid.) on a site adjacent to the previous one. Trees are dying in groups along the edge of the plantation.

Fig. 3. 21-year-old Scots pines showing a devastating attack by *F. annosus* Fr. 7 years after a heavy thinning.

Fig. 4. An adjacent plot of 21-year-old Scots pines, which were not thinned and remained healthy.

Fig. 5. A small Scots pine (*Pinus sylvestris* L.) killed by *F. annosus* Fr., showing its root system in contact with infected stump roots (↑).

Fig. 6. A small sporophore of *F. annosus* Fr. at the base of a 20-year-old Corsican pine (*Pinus nigra* var. *calabrica* Schneid.), whose crown was still living.

THE RELATION BETWEEN SOIL CONDITIONS, TYPE OF GROUND VEGETATION, AND THE GROWTH OF TREES

By W. R. DAY

(*Department of Forestry, University of Oxford*)

INTRODUCTION.

IT is a matter of common experience that under conditions the nature of which are at present ill defined, forest trees suffer from a more or less severe chronic chlorosis during the early stage of their development. This chlorosis is caused fundamentally by nutritional deficiency, and sometimes has been linked up with the absence, at least in adequate quantity or suitable form, of particular nutrient elements (3). There are, however, numerous cases in which the chlorosis, although perhaps enduring for a time as a chronic condition, eventually disappears, or at least becomes much alleviated and relatively insignificant. In these cases it can usually be demonstrated that the causal factors are directly related to the competition of the ground vegetation for food and water, the chlorosis being relieved if such vegetation is suppressed, whether by mulching or other form of cultivation. This type of chlorosis is not confined to artificially regenerated woodland: it may appear equally in the naturally regenerated. Also, one species may show the condition markedly, when another growing side by side does not. Thus, for example, Norway spruce (*Picea abies* Karsf.) on poor moorland soils may show marked chlorosis when Sitka spruce (*Picea sitchensis* Carr.) does not, even when the two are planted in alternate lines. The presence of this chronic chlorosis is undoubtedly associated with a relatively poor rate of growth; but this does not mean that it appears necessarily only on trees of which the growth is in a state of check. Nor do trees in check necessarily show it; for example, in Carmarthenshire Sitka spruce growing on ground dominated by ling (*Calluna vulgaris* L.) were in check and chlorotic, whereas in an adjoining area, on ground dominated by dwarf gorse (*Ulex minor* Roth.), they were growing equally poorly but were not chlorotic. The exhibition of this chlorosis may thus vary from species to species growing under similar conditions, at least in the degree to which it is shown; and also for the same species according as soil and vegetation vary. The general indications are that it appears under conditions which tend, at least at times, to be marginal for growth, whatever may be the reasons for these conditions. The isolation of this type of chlorosis from that which is directly associated with an insufficiency in the soil of one or more nutrient elements is purely a matter of convenience in discussion. All species of tree are probably susceptible to it, under appropriate conditions, although some appear to be more so than others: for example, Scots pine (*Pinus sylvestris* L.) seems generally to be less susceptible than either Sitka or Norway spruce. Some examples will illustrate both the range of species affected and the conditions within which it may be observed.

(*a*) *Calcareous (chalky) soils covered with dense turf.*

Hawthorns (*Crataegus oxyacantha* L.) which have naturally colonized such soils may be markedly affected. Not only are their leaves a yellowish-green but they frequently fall early. If this type of land is afforested, seedling hawthorns which develop under the shelter of the planted trees, once these are established, show leaves of a normal green colour, which are held until the autumn.

European larch (*Larix decidua* Mill.), ash (*Fraxinus excelsior* L.), and beech (*Fagus sylvatica* L.) provide examples of economic forest species which are affected in the same way. The condition may persist for a long period of years, during which the affected tree grows slowly and poorly. It is relieved by any treatment which suppresses the turf. For example, on the South Downs it has often been observed that where brambles spread out, usually from a rabbit warren, so that trees affected by chronic chlorosis become surrounded and the turf in which they stand is suppressed, a normal colour develops in the trees and more rapid growth ensues. A mulch of soil washed down a slope from a warren will act in the same way. Trees affected may attain normal colour and growth rate before canopy closes, and without any aid from cultivation, if soil conditions are sufficiently good. When this takes place it has been observed, in the case of European larch on black rendzina soils, that the development of normal appearance and vigour was accompanied by the appearance of marked fungus growth in association with the roots. The white mycelium could be observed quite easily in the dark-coloured soil. It is not improbable that some change in the balance of the soil fungus flora, which this indicates, is a normal occurrence as chlorosis passes.

(*b*) *Brown Forest soils with impedance in the subsoil.*

Heavy clay-loams of this type are not infrequent in some parts of the midlands of England. They commonly develop a strong growth of tussock grasses (*Deschampsia caespitosa* Beauv. or *Calamagrostis epigeios* Roth.), especially when shallow and free of woodland or left ungrazed. Poplars (*Populus* spp.) planted into this vegetation have shown chronic chlorosis to a marked extent. Oak (*Quercus* spp.) have been similarly affected, even in the presence of less strongly growing grasses than the above. It has been proved, in the case of poplar, that mulching sufficiently heavily to suppress the ground vegetation results in the attainment of normal colour and the assumption of an improved growth rate.

(*c*) *Soils of Brown Forest type, sometimes showing more or less leaching, and usually freely draining and dominated by* Calluna vulgaris *L., if unafforested and left uncultivated.*

European larch has not infrequently been planted on soils of this type in the west and north of Britain. It shows chronic chlorosis fairly consistently and often markedly. Good examples are to be found in parts of Wales, in the Lake District, and in a number of places in Scotland; Clashindarroch Forest in eastern Aberdeenshire at present provides good and extensive examples. Spruces planted on this type of ground also show the chlorosis and grow slowly unless some sort of cultivation

is given. These soils, in fact, are rather adverse to the establishment of some species of forest tree; but in the case of spruce, at least, it is known that suppression of the ground vegetation, as by ploughing, is markedly favourable to the trees.

(*d*) *Podsolized soils with impedance in drainage in the subsoil.*

An excellent sample of European larch (*Larix decidua* Mill.) established by natural regeneration after clear felling, on a soil of this type, was seen recently in Darnaway Forest, Morayshire, Scotland. The ground vegetation was characterized by *Calluna vulgaris* L., *Vaccinium myrtillus* L., and *Deschampsia flexuosa* Trin. These natural larch seedlings, some of which were 5 or 6 years old and plainly well established, all showed chronic chlorosis, markedly. This was interesting for two reasons. First, young larch plantations which grow near by on a deep, well-drained Brown Forest soil of morainic origin had made excellent growth and were of a most beautiful deep-green colour. Second, the area naturally regenerated had born a mixed crop of European larch and Scots pine (*Pinus sylvestris* L.), a remnant of which still stands. At 80 years old the larch are probably 100 feet high. Evidently, in spite of the signs of adversity shown by the young trees, this ground can grow quite good larch, even though it may be inferior in vigour of growth, compared with that which until recently stood on the more fertile Brown Forest soils.

These examples are sufficient to show that under some conditions deficiencies in nutrition arise in young trees, and that under these circumstances relief from competition from the ground vegetation is a decided advantage. One of the ways in which this relief may be obtained is by growing a species which is more susceptible to competition with one which is less susceptible and therefore reaches relatively soon a stage in which it is able to dominate the ground vegetation constituting the adverse competing factor. This is a matter with which Robinson (6) is concerned when discussing the value of pines in stimulating the growth of other species of conifer, and especially spruces. The technique is an ancient one in forest practice and is a method of extending the ecological range of a species which is relatively valuable economically. It has been seen in operation in private estate forestry in the many mixed plantations, e.g. of pine, spruce, and larch or of pine and larch, which have been raised in the past. It has always been difficult, however, to find woodland in which any adequate comparison could be made between pure plantings and mixed plantings made on soil on which chronic chlorosis tends to occur. Small areas of line-by-line mixtures of Scots pine and European larch do occur in Clashindarroch, side by side with pure European larch, and during a recent tour of larch plantations in Scotland the opportunity was taken to make a few assessments in each type of planting. The results of these are given in Tables I to IV. The places of origin of the seed used in these plantations are given in Table V.

The samples from which the data were collected consisted of 10 trees, each taken in a line. Any dead trees encountered were rejected, though recorded if present. The samples were taken in pairs, adjacent to each other on either side of the line dividing the mixed from the pure planting. No attempt was made to

TABLE I. *Comparison of Total Height, Length of Leading Shoot, and Number of Dead Trees, in Mixed and Pure Plantings of European Larch* (Larix decidua *Mill.*)

EL = European larch; SP = Scots pine (*Pinus sylvestris* L.)

Compt. no.	*Planting year*	*Pairs of plots*	*Mean total height (ft.)*		*Mean length of leading shoot (in.)*		*No. of trees discarded because dead*	
			EL	*EL+SP*	*EL*	*EL+SP*	*EL*	*EL+SP*
64	1932	A	10·0	10·3	13·8	11·2	3	..
		B	9·9	10·0	8·5	14·1	2	..
78	1933	A	7·3	10·6	16·5	16·7	..	..
		B	9·2	11·6	12·9	16·5	..	..
		C	9·8	10·9	11·1	16·2	2	..
174–5	1938	A	7·2	9·1	11·1	12·9	..	..
		B	7·1	8·2	9·6	12·9	1	..
		C	7·8	7·0	11·4	10·0	..	..

Each measurement is a mean of a sample of 10.

TABLE II. *Assessment of Condition of Main Stems in relation to Canker* (Dasyscypha)

EL = European larch (*Larix decidua* Mill.); SP = Scots pine (*Pinus sylvestris* L.)

Crop	*Compt. no.*	*Planting year*	*No. of trees with stems*			X^2	*P*
			Good	*Moderate*	*Poor*		
EL	64	1932	7	6	7	1·17	0·50 approx.
EL+SP	64	1932	4	8	8		
EL	78	1933	5	11	14	12·30	Between 0·01 and 0·001
EL+SP	78	1933	17	9	4		
EL	175	1938	6	13	11	0·60	Between 0·80 and 0·70
EL+SP	174	1938	5	16	9		

Good—Trees with canker only near ground level, or none at all.
Moderate—Trees with one or two cankers on the stem.
Poor—Trees with stems cankered throughout.

X^2 is an index which measures the degree of difference between the frequencies with which characteristics occur in particular groups which, by hypothesis, should be similar: i.e., it is a means of testing the agreement between observation and hypothesis in regard to numbers of things having particular attributes.

P represents the chance, expressed as a proportion of unity, that differences such as those exhibited here between the sets of figures compared are likely to occur again if a second sample were taken in a population in which the characteristics observed were distributed completely independently of each other.

References (any one of which may be consulted): Fisher, R. H., *Statistical Methods for Research Workers*, 8th ed., London, 1941; Goulden, C. H., *Methods of Statistical Analysis*, New York, 1939; Mather, K., *The Methods of Statistics*, 2nd ed., London, 1946; Snedecar, G. W., *Statistical Methods applied to Experiments in Agriculture and Biology*, Ames, Iowa, 1946; Tippett, L. H. C., *The Methods of Statistics*, 2nd ed., London, 1937.

choose systematically the site of any pair of observations along any such line, except that in Compartment 64, where the crop is very uneven, the comparisons were taken in the better parts. The larch in this compartment and in No. 78 are of mixed provenance, some being raised from Scottish and some from Swiss (Münsterthal) seed. The Swiss larch of this strain is known to be unsuited for growth in Great Britain and particularly susceptible to disease, although in its native habitat it grows well.

Table I records that, taken as a whole, the mixed plantings show rather better height growth than the pure, whether this is judged by total height growth or length of leading shoot. Also, all the eight dead trees which occurred among the total of those observed were in the pure plantings. No attempt was made to determine the statistical significance of these results, because it was felt that a more extensive sampling was needed before a clear conclusion could be come to, in any case. The figures suggest, however, that, on the whole, growth of larch is better in the mixed than in the pure plantings.

Table II shows that in Compt. 78 there is a significant association between freedom from canker on the main stem and mixed planting; but in the other two compartments there is no sign of any such association. Again a more extensive sampling is necessary.

TABLE III. *Assessment of Conditions of Leading Shoots*

EL = European larch (*Larix decidua* Mill.); SP = Scots pine (*Pinus sylvestris* L.)

Crop	*Compt. no.*	*Planting year*	*Number of trees with leading shoots*				
			Good	*Moderate*	*Poor*	X^2	*P*
EL	64	1932	1	17	12	15·04	0·001
EL+SP	64	1932	12	5	3		
EL	78	1933	12	6	12	12·05	Between 0·01 and 0·001
EL+SP	78	1933	21	8	1		
EL	175	1938	15	8	7	2·67	Between 0·30 and 0·20
EL+SP	174	1938	21	4	5		

Good—Leading shoots perfect for 3 years back.
Moderate—1 year's growth killed back.
Poor—2 years' growth killed back.

Tables III and IV show that in the older crops (Compts. 64 and 78) there are significant associations between growth in mixture and freedom from loss of leading shoot and freedom from die-back in the upper half of the crown. No significant association is indicated for the younger crop (Compts. 174–5). Thus the suggestion is that growth in mixture has had a significant effect in relieving the intensity of disease, but that this may not appear until some years after planting has taken place: probably it begins to develop strongly only after canopy is formed appreciably by the less susceptible species, in this case Scots pine. The length of this period, on any given site, may be affected by the density of planting,

TABLE IV. *Assessment of Damage to Upper Half of the Tree in relation to Die-back*

EL = European larch (*Larix decidua* Mill.); SP = Scots pine (*Pinus sylvestris* L.)

Crop	Compt. no.	Planting year	Number of trees with die-back in upper crowns				X^2	P
			Nil	Slight	Moderate	Bad		
EL	64	1932	..	..	7	13	17·58	0·001
EL+SP	64	1932	1	11	4	4	..	..
EL	78	1933	9	5	7	9	10·98	Between 0·02 and 0·01
EL+SP	78	1933	14	5	11	..		
EL	175	1938	1	14	9	6	0·51	0·95 approx.
EL+SP	174	1938	2	13	8	7	..	..

TABLE V. *Seed Origins of European Larch in the Compartments under Observation* (Larix decidua *Mill.*)

Compt. no.	Seed id. no.	Place or region of origin
64	28/30	Münsterthal, Switzerland
	29/79	Scotland (E)
78	30/28	Münsterthal, Switzerland
	30/75	Scotland (E)
174	35/143	Morayshire
	35/147	Kirkhill, Aberdeenshire
175	35/143	Morayshire
	34/74	Scotland (SE)
	34/84	Scotland
	34/87	Richmond & Gordon, Morayshire

since this must affect the time at which suppression of ground vegetation begins. It must be noted, however, that Compts. 174–5 contain no Münsterthal larch and that a difference in reaction may be due to this difference in provenance, at least in part (Table V).

The opinion of the working party as a whole was that the chlorosis was more marked in the pure plantings, irrespective of age. A deeper green of larch growing on better and probably more consistently moist soils was also noted in this forest.

These results are not in themselves of any very great significance. But clearly they do suggest that where chronic chlorosis occurs on soils dominated by *Calluna vulgaris* L., mixed planting of European larch with Scots pine may be much to be preferred to pure planting. Plainly, further investigation is needed before this can be proved conclusively in a quantitative manner, and it is hoped that further observations will be possible in the future.

Too much is not to be expected from regulation of mixture in planting as a means of controlling larch die-back and canker, for it is known that even under the best edaphic conditions larch may be seriously susceptible to this disease, if the

local climatic conditions are unsuitable. Nevertheless, when the provenance of larch is reasonably suited to the region, attention to the manner of growth and the ecological value of accompanying species may become of considerable importance. There is no clear evidence, at present, that any particular provenance of European larch is less susceptible to this chronic chlorosis than are others; but it does seem to be true that the more vigorously growing and disease-resistant types come out of it more quickly than others.

DISCUSSION.

Consideration of cases in which chronic chlorosis occurs shows that a number of factors may interact in causing its development. Any chlorosis of the type under discussion necessarily arises owing to nutritional deficiencies. But it would seem that these may occur when there is no critical lack of nutrients in the soil, however little available they may be to the plant. The Brown Earth creep soils in Clashindarroch Forest, on which both European larch and Norway spruce (*Picea abies* Karst.) show chronic chlorosis, seem to provide a clear example of this, judging by the data given by Muir and Fraser (4). Under these circumstances other important causal factors need to be looked for, and some of these seem clearly to be related to the volume of soil available for rooting, and the competition for rooting space within this soil. It can be shown that soil depth, as the variable factor which under any given conditions determines soil volume, has a determining influence on rate of height growth, even when the soil is fertile and competitive effects during the first years are of no great significance (1, 2). It seems always to be characteristic of soils which are shallow and yet fertile, as judged by height increment during the early years of growth, that they are well aerated, usually moist within the main rooting-layers, and biotically active, as well as showing no critical nutrient deficiency. When chlorosis occurs, one or more of these conditions seems to break down: sometimes it is quite obvious that this is so. For example, in central Wales moorland soils occur which bear a poor vegetation dominated by *Nardus stricta* L., *Deschampsia flexuosa* Trin., and *Vaccinium myrtillus* L., with some *Calluna vulgaris* L. They show impedance in drainage up to or very near the surface of the mineral soil, and carry a thin layer of raw humus. The rooting depth of spruce planted on such soils is extremely shallow, and mainly in the raw humus in many cases: both Sitka and Norway spruce remain in check for many years after planting, and the latter, in particular, shows marked chlorosis. Sometimes, however, as at Clashindarroch (4), pedologists have concluded that the soils are reasonably fertile and the growth of older trees may show this to be the case. In these less obvious cases, also, it would appear that it is necessary to look for the cause of the chlorosis in some factor related to competition by the ground vegetation, which restricts the root development of the tree within a limited rooting space. Table VI gives some examples of such soils: their main rooting-depth is shallow and the subsoil is markedly unfavourable to efficient root action, even if root growth takes place within it, whether, in the cases cited, because of excessive stoniness (lack of soil) combined with free drainage (Nos. 1 and 2), or strongly impeded drainage (Nos. 3 and 4).

TABLE VI

No.	Forest	Species affected	Soil					Vegetative type
			Group	Drainage	Slope	Depth* (in.)	Character of lower layer	
1	Buriton	European larch, (*Larix decidua* Mill.) Beech (*Fagus sylvatica* L.)	Chalky rendzina	Free	Slight–moderate	4–6	Chalk and flint stones over hard chalk	Downland turf
2	Clashindarroch	European larch, Norway spruce (*Picea abies* Karst.)	Brown Earth	Free	Moderate–steep	6–10	Stones with more or less soil in interstices	*Calluna vulgaris* L.
3	Rockingham	Hybrid Black poplar (*Populus* sp.)	Brown Earth (gleyed)	Impeded	None or slight	15–18	Heavy fissured clay	Large tussock grasses
4	Darnaway	European larch	Podsol (gleyed 'B')	Impeded	None or slight	13–15†	Clayey glacial drift	*D. flexuosa* Trin. *V. myrtillus* L. *C. vulgaris* L.

* The depth of soil containing few or no restrictions to root development. † Includes 4 in. of raw humus.

The value to the planted crop of suppression of the ground vegetation on such soils plainly must lie in the degree to which more adequate root development can take place within the shallow soil layers in which, for physical reasons, it is alone possible to any effective extent. The importance of this is stressed by the frequency with which the stratification takes place of tree roots in relation to those of the ground vegetation. The latter, having been in possession at the time the trees were planted, occupy usually the most favourable soil layers; the roots of the introduced trees frequently are to be found mainly below the roots of the ground vegetation, and also in the humus or litter on the soil surface, if it is moist enough and present in sufficient quantity. Thus, poplar (*Populus*) sets planted in shallow boulder-clay soils covered with tussock grasses at first root mainly in the gleyed layer beneath the grass roots, which dominate strongly in the better-drained and much more fertile surface layers. Similarly, European larch planted into ground covered with ling (*Calluna vulgaris* L.) often, though not always, develops its root system mainly below the ling roots, and usually also to a certain extent in the surface covering of humus. On the other hand, if a species is growing healthily and without check it seems always to root in with the ground vegetation and to be able to compete with it, or if stratification occurs, it does not tend to be long maintained, owing to the suppression of the ground vegetation by the successful growth of the trees.

All chronic chlorosis is pathological and relates to a state which arises owing to ineffective root action or development. Now the roots of trees do not act in a sterile nutrient medium but in close association with the soil microflora, with some species of which the feeding roots form mycorrhiza. It has been demonstrated that under appropriate conditions effective root development may fail if a mycorrhiza-forming fungus suitable to the species of tree is absent (5, 7). It is interesting, therefore, to ask whether trees which show this chlorosis are unable to form effective mycorrhizal associations. There has been very little work done on this point, but sometimes, at least, it is quite clear that this is not the explanation. The writer was interested in some Sitka spruce which grow in Carmarthenshire in shallow soil of a Brown Earth type, covered by vegetation in which bracken (*Pteris aquilina* L.) or ling (*Calluna vulgaris* L.) are variously the dominant plants. The height growth of the spruce is significantly correlated with the depth of the soil, and so is the dominance of bracken or ling. The spruce is still in check, after about 15 years, on the places where the soil is very shallow, and it is in these places that ling dominates strongly; the bracken is the dominant where the soil is deeper. Examination (by Dr. Levisohn, to whom thanks are due) showed that the trees had well-developed and healthy roots, with good mycorrhizal associations in the humus layer, irrespective of the height of the tree, or whether this was growing very slowly or relatively fast. This was not true, however, of the roots in the mineral soil (*A* horizon). There the number of short feeding-roots was much less abundant, but where the trees were in canopy and growing healthily, these roots were of good type. The trees in check, however, had very few and poorly developed short roots in this soil. Now it is quite plain that here the poor growth was not related to the absence of appropriate mycorrhizal fungi;

therefore it must have been due to some more fundamental condition, which in this case seems quite clearly to be related to shallowness of soil available for root growth. One other point is perhaps of interest. The root growth in the humus was equally good whether the humus was derived mainly from the debris of ling, as where the trees were in check, or whether it consisted mainly of spruce needles and bracken fronds, as where the better tree growth was being obtained.

The proper understanding of problems such as chronic chlorosis necessarily awaits the analysis of situations in which a number of factors act together, so that the influence of any one cannot be appreciated properly unless that of the others is taken into account. The function of the investigator, in diagnosis, is to estimate, in any particular situation, what aspect of this interacting complex of factors holds the key to the pathological development. This is of particular importance in forest management because it is only by the appreciation of this function that effective action is likely to be taken to use or treat soils which, at least at first, tend to be difficult for tree growth, or at the worst may never produce a forest of economic value. The cases discussed suggest that often some of the most important adverse factors are physical and are to be found in such things as an unduly limited amount of soil that is good for rooting, and in the state of the water/air balance in that soil. The nutrient status of the soil per unit volume comes in as affecting the efficiency of the soil volume for root action; and the biotic soil factors are to be seen acting against the predominating physico-chemical framework. The factors limiting growth are to be found in the essential character of this framework.

Thanks are due to the Forestry Commission, and especially those members of its research staff who made possible the collection of the data relating to European larch in Clashindarroch Forest.

SUMMARY.

It is shown by reference to examples that under relatively adverse soil conditions forest trees tend during early life to suffer from a chronic chlorosis caused by the competition of the ground vegetation. The chlorosis is relieved by suppression of this vegetation, either by some form of cultivation or by mixing the susceptible species with one less susceptible to the effects of the competition. European larch (*Larix decidua* Mill.) is one of the species affected. Observations made in pure plantings of this species, affected by chlorosis, and in adjacent plantings in which Scots pine (*Pinus sylvestris* L.) was mixed with the larch, line by line, suggest that not only is the chlorosis less severe in the mixed plantings but also these are healthier and, probably, rather more vigorous in growth. It is suggested that physical factors related to the volume of soil effectively available for rooting and especially, perhaps, to the water/air balance within that volume, are of particular importance in determining the development of the chlorosis.

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THE ESTIMATION OF FIRE HAZARD IN GREAT BRITAIN

By T. R. PEACE
(*Forestry Commission*)

INTRODUCTION.

IN countries where forests are very large in extent, and where the climate is inclined to reach extremes of heat and drought, fire losses will justify the adoption of any proven methods likely to reduce their incidence or limit their spread. In Great Britain, on the other hand, as forest areas are comparatively small and the climate is seldom extreme, and is notoriously inconstant, fire-protection measures require careful consideration before they are adopted. But whatever the conditions of forest area or climate, a considerable saving of man-power and money can be made by increasing fire precautions only as the hazard increases, and relaxing them as it falls. In Great Britain this has always been done according to the personal judgement of the local forest officers and foresters; but in North America, and to a lesser extent in other countries of high fire danger and large forest areas, personal judgement has not been considered sufficiently reliable, and methods of evaluating the fire hazard from meteorological and other data have been devised. The values thus calculated have been used not only to control the degree of precaution taken, but also as the basis of warnings to the public. A very good review of the work done on fire hazard has been made by Wright and Beall (8). Their bibliography of 110 titles, all but 7 of them American, gives some idea of the amount of work that has been done on this subject.

Early in 1941 the author, then stationed in the Forest of Dean, where small fires are frequent, decided that it would be of interest and possibly of actual value to see how fire-hazard estimation behaved in this country. Details of the method elaborated by Wright and Beall (7), and in use over much of Canada, were readily available, and in the first place this method alone was under test. Readings were started on 28th March 1941. It so happened that, anticipating enemy efforts to set crops on fire, the Meteorological Office had started to issue warnings designed to tell farmers the degree of danger, should incendiary attack take place. At the request of the Forestry Commission, the method of calculation was altered slightly to make it more applicable to forest conditions, and for 2 years warnings were issued to Forestry Commission personnel during the more dangerous seasons, on a wide regional basis. By the kindness of the Director of the Meteorological Office, records of these warnings have been made available, and are compared below with the hazard calculated by the Canadian method.

Early in 1942 it was decided that it was desirable to have some other basis of comparison. The best would undoubtedly have been trial fires, but lack of time and labour rendered this impossible. So six of the most experienced foresters in

the area were asked to note each day their personal estimation of the fire danger, and an average of their opinions was used for comparative purposes. Note was also kept of the occurrence and severity of all the fires that took place in the Forest of Dean, but for reasons which will be explained later these can hardly be regarded as a satisfactory check on fire-hazard estimations. Observations using the Canadian method were carried on from 28th March 1941 to 30th April 1945, though they were discontinued for varying periods each winter. Meteorological Office warnings were issued from 23rd March 1942 to 11th July 1943, with the omission of June and July 1942 and of the winter. The foresters' estimates started on 3rd April 1942, and covered the remaining periods when the Canadian system was in operation; but after the first year enthusiasm waned, and only one or two foresters continued to keep records. Records of actual fires are available for the whole period covered by the Canadian method.

The usual acknowledgements at the end of a paper are quite insufficient to cover the share which Mr. C. W. Barfoot took in the work, and only considerations of distance, and the time that has elapsed since his connexion with the work was severed, have prevented him from appearing as joint author of this paper. He was entirely responsible for setting up the rather specialized meteorological station required, and for the adaptation of Wright and Beall's Canadian tables for use in this country. Without his assistance the author could never have undertaken the mathematical complexities involved in this adaptation, nor the routine work involved in the collection and working out of the daily readings.

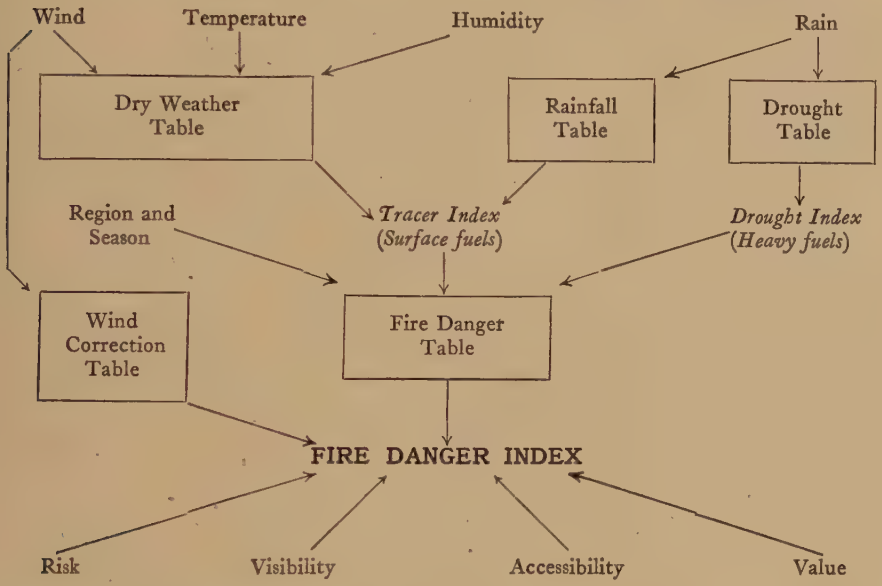
THE CANADIAN METHOD.

The method used was that elaborated by Wright and Beall (7), in which a 'Tracer Index' representing the moisture content of forest fuels was calculated from meteorological records of evaporation, temperature, rainfall, and humidity. Once readings were started and as long as they were continuous, this 'Tracer Index' was never recalculated, but was only modified from day to day. From the 'Tracer Index' a Fire Danger Index was calculated on the basis of the region concerned (different regions have different fuel types), and the season of the year, in so far as it affects the condition of the vegetation. The Fire Danger Index was subsequently modified for the effect of wind on a fire once started, and for the cumulative effect of drought, as it gradually dried out the deeper layers of inflammable material. The final Fire Danger Index was still subject to personal modification with regard to factors difficult to evaluate mathematically, such as risk (presence of railways, public holidays, &c.), accessibility, visibility (in connexion with spotting fires), and the value of the crop.

In a further publication, which appeared too late to be used by the author, Beall (2) has considerable simplified the method. His new tables no longer require the duration of rainfall, and an ordinary rain gauge can now be used instead of a recorder. Evaporation is no longer measured, its effect being covered by considering humidity and wind in conjunction. In this publication a table is given, reproduced on p. 197, which shows very clearly the way in which the

various factors are used to produce and modify the 'Tracer Index' and subsequent Fire Danger Index.

The use of the modifiable 'Tracer Index', instead of fresh daily calculation, is mainly and successfully designed to lessen the tendency for sudden variations in the Fire Danger Index. Any more direct method tends to attach an undue effect to slight rains or to sudden increases or decreases of wind, and it is obviously undesirable to reflect such changes in sudden modifications of precautions.



The Fire Danger Index as calculated by the Canadian method is not in any sense a forecast. It is based on meteorological readings over the last 24 hours, and is applicable to the following 24 hours only if there is no major change in weather conditions. It is possible to work it on a forecasting basis, using expected instead of actual values. The method of doing this is described by Beall (1). In the author's case no official weather forecasts were available, as they were discontinued during the war. It was not considered that home-made forecasts would be sufficiently accurate to provide a fair test of the method, and in practice it was used entirely on the basis of actual measurements. In any case it would be a rash forester who relaxed his precautions in response to a forecast of lessening fire danger, though there are obvious advantages in having forecasts of weather conditions likely to increase fire danger.

The Canadian Fire Danger Index can have any value from 0 to 16. These values represent:

0. No hazard. Fires unlikely to start; fires already burning may not go right out, but will not spread.

1 to 4. Low hazard. Fires spread slowly from robust fires and other large sources of heat; but are easily controlled.

5 to 8. Moderate hazard. Fires often start from matches and tend to spread more rapidly as they increase in size. Control is not usually difficult, if action is prompt.

9 to 12. High hazard. Fires start readily from matches, and may start from embers or cigarette-butts. Rate of spread is rapid and control difficult.

13 to 16. Extreme hazard. Fires may start from small sparks; they burn fiercely and small fires frequently start ahead of the main fire. Conditions are often called explosive.

As will be discussed later, it is probable that extreme hazard is seldom, if ever, attained in this country. Apparently in Canada basic precautions, such as the manning of the most important look-outs and the patrol of the main routes, are started when the hazard becomes low; for moderate danger all look-outs and patrols are manned but only a skeleton fire crew is ready for immediate duty; high danger puts the full fire-precaution system into a state of preparedness; while during extreme danger virtually the whole forest labour force is ready for immediate action.

In the author's work the following readings were taken daily at 9 a.m.: rainfall over the previous 24 hours, from a recording rain gauge (a home-made instrument constructed by C. W. Barfoot), as the Canadian tables required information on the duration of rainfall, and the time of day at which it fell, as well as on the depth recorded: evaporation for the previous 24 hours, from an exposed water surface, using a special type of evaporimeter devised by Wright (in the first instance a home-made instrument was used, but this was later replaced by a standard evaporimeter kindly supplied by the Canadian Forest Service): relative humidity from a recording hygrometer, which was checked frequently against dry- and wet-bulb thermometers, the average of the lowest two hours during the previous day being the figure used: the wind velocity calculated by reading an anemometer at 8.30 a.m. and again at 9 a.m. Wright and Beall's tables were used with only very minor alterations, with the exception of that for calculating the Fire Danger Index from the 'Tracer Index'. They used a large number of tables applicable to different forest types at different times of year. C. W. Barfoot prepared a provisional table, applicable, it was hoped, to the mixed forest types which occur in the Forest of Dean and widely over the south of England, and including allowances for seasonal differences in the state of the vegetation.

There is no doubt that this method was rather complicated, involving, as it did, a considerable number of meteorological readings, and a considerable number of quite straightforward calculations, using six separate tables. In the hands of anyone with an even slightly mathematical mind it had no terrors, but to the uninitiated it appeared impossibly fearsome. It is considered that using the more recent simplified tables and given proper coaching it would be within the competence of any forest officer and any forester with a reasonable educational background.

THE METEOROLOGICAL OFFICE METHOD.

It is hardly possible to describe the method of calculating fire danger adopted by the Meteorological Office without quoting it in full, which is done below, by permission of the Director. It is only fair to point out, as the method is subject to considerable criticism below, that it was produced under emergency conditions in response to a sudden demand.

I. Find the evaporation E for each of the last 6 days from the formula:

$$E = 0{\cdot}3v + 2(t - t_1),$$

where v is the wind velocity in m.p.h. and

$(t - t_1)$ is the difference between the dry- and wet-bulb thermometer readings, the observations being taken at 13 h. G.M.T.

II. Find the rainfall R for the 24 hours ending 7 a.m. each morning. (The value R_1 will be a forecasted value.)

Form the sum:

$$X = (E_1 - R_1) + \tfrac{4}{5}(E_2 - R_2) + \tfrac{2}{3}(E_3 - R_3) + \tfrac{1}{2}(E_4 - R_4) + \tfrac{1}{4}(E_5 - R_5) + \tfrac{1}{16}(E_6 - R_6),$$

where the suffixes indicate the number of days preceding the day for which the index is being prepared.

For example, if the index refers to the 13th day of the month, E_1 and R_1 refer to the 12th of the month, E_2 and R_2 to the 11th, E_3 and R_3 refer to the 10th, and so on.

III. Finally the index I is calculated from the following formula:

$$I = X.W.C.\tfrac{1}{2}(V + 4)\frac{1}{3}\left(1 - \frac{H}{100}\right),$$

where W = estimated weather *at the time to which index applies*
- = 0·0 for rain or thick drizzle
- = 0·1 for light rain or drizzle
- = 0·5 for overcast sky (low cloud)
- = 0·7 for broken low cloud, 3–8 tenths
- = 1·0 for low cloud 0–2 tenths

C = a factor to allow for dew.

The value of

C = 1 if W is less than 1.

But if

W = 1, then
- $C = \frac{1}{2}$ for night or early morning
- $= \frac{3}{4}$ for morning or afternoon
- = 1 for mid-day

V = estimated wind speed at 20 feet above the ground

H = estimated relative humidity of the air at the time to which the index applies. H and V refer to the time at which the most favourable conditions (i.e. highest index) occur in the night and day following.

IV. If the forecaster, from his assessment of the conditions which have prevailed and are expected during the 24 hours following the time of issue of the forecast, considers that

the degree of suitability ought to be put up or down a point, he should do so; for example, if there is appreciable rain of the order of 5 mm. on the day the forecast is issued, i.e. during the 24 hours ending at midnight on that day, a previous high evaporation should be partially discounted unless dry conditions and appreciable wind are going to follow immediately and dry up the rain before the expiration of the period covered by the forecast.

It will be seen that in this system the fire danger calculated is a forecast, but is nevertheless to a considerable extent dependent on previous and present weather conditions. It was found possible to base it entirely on actual records, making R_1, W, V, and H actual, instead of estimated, values, and for comparative purposes this was done for part of 1941, using the meteorological data collected for the Canadian method. Except in 1941, therefore, differences in the values produced by the two systems may be due not only to differences in method but also to unavoidable occasional incorrect forecasts on the part of the Meteorological Officer. In addition, the Meteorological Office warnings covered quite large regions, in this case Cornwall, Devon, Somerset, Wilts., and Gloucester, so that they could hardly expect to be accurate for the whole area, especially since the Forest of Dean is on one edge of it, and owing to its topography has to some extent its own climate. It was found possible to draw up tables covering most of the calculations involved in this method, and these made it mathematically no more difficult than the Canadian method.

This system gave a final figure ranging from 0 to 20. The actual warnings were given in five degrees of danger only as under:

0 to 1.	Negligible
2 to 5.	Slight
6 to 10.	Moderate
11 to 19.	Serious
Above 20.	Very serious.

In the figures which C. W. Barfoot calculated for 1941 the actual basic values were used, but were divided by 1·33 so that they ranged from 0 to above 15 instead of from 0 to above 20, and so that they fitted into the 1–16 scale used for the Canadian method. It was at first assumed that when the five degrees of danger were used, they could be considered as equivalent to the five divisions of the Canadian system, but when it had been discovered that in the Forest of Dean the Canadian system never gave values higher than 12, it was considered that this should be the equivalent of 'very serious' in the list above, and for graphical purposes the five degrees listed above were given arbitrary values 0, 3, 6, 9, and 12.

It is extremely doubtful whether the joint effect of various weather factors on forest fire danger can be expressed by a fairly simple product formula, such as is employed above. All other methods have aimed primarily at estimating or actually measuring fuel moisture content (represented by the 'Tracer Index' in the Canadian method) and then adjusting it for factors such as wind velocity and time of year. Since the Meteorological Office method was developed in the first instance to deal with fire hazard for mature cereal crops over a comparatively short period of the year, no question of introducing modifications to cover

differences of vegetation type or development arose. Even when the system was altered to meet forest requirements, nothing of this kind was introduced, so that fuel types and the state of the vegetation required personal modification of the figure arrived at by calculation. It will be noticed that individual modification on rather vague grounds is allowed in the official instructions, so that the final figure arrived at would be subject to considerable possibility of personal error. In the author's use of this method for comparative purposes no correction was made for seasonal or for vegetational types, so that the system is to that extent at a disadvantage in comparison with the Canadian method, where these factors were allowed for in the tables used for calculation.

As will be discussed later, the Meteorological Office method gives very rapid fluctuations, low wind or slight rainfall bringing it down, and high wind sending it up too far. Obviously such fluctuations are neither real nor desirable when considering questions of administration based on hazard. In an effort to iron out these fluctuations C. W. Barfoot applied a cumulative drought factor, similar to that used by Wright and Beall, to the Meteorological Office calculations. This had a distinct smoothing effect, but the hazard figure still fluctuated more than weather changes seemed to justify.

It is doubtful whether the correction for dew takes quite the most desirable form. In the Canadian method no direct allowance is made for dew, and it only influences the Fire Danger Index indirectly in so far as it affects relative humidity and evaporation. On the other hand, the author found that in September, when heavy dews lowered what would otherwise have been quite a high hazard, calculations on the Canadian method, with no dew allowance, gave too high a danger. Earlier in the year, however, there was no indication that a dew allowance was required. Certainly a modification whereby C, the dew factor in the Meteorological Office system, becomes 1 for afternoon as well as midday, is required, as by general experience danger is greatest in the afternoon and dew evaporates progressively until the evening. That the late afternoon and early evening is the worst period for forest fires is borne out by Edlin (4), though of course the factor of increased human activity at that time of day also has its effect.

OTHER METHODS.

It is not intended in this paper to enter into any detailed discussion of methods not actually used by the author. These are covered very adequately by Wright and Beall (8). But a consideration of the subject would be very incomplete unless some mention was made of the method widely in use in the United States, whereby fuel moisture is measured by the actual weighing of standard sticks exposed to the weather, and this value is subsequently modified for wind velocity, condition of the vegetation, and the number of days since 0·5 inch or more of rain fell (cumulative drought factor). Such a method is described by Jemison (6). Since no comparative figures appear to be available, and since it has not been tried by the author, no useful comment can be made on its accuracy as compared with Wright and Beall's method. It has, however, the obvious attraction of requiring fewer observations and instruments. The subsequent amendments to the fuel

moisture content figure are made by a very simplified slide-rule system, in which one card slides behind another, and set according to vegetation and other conditions in one slot, gives the correct fire-danger index for those conditions in another. The working out is therefore relatively much more simple than for either of the methods so far described.

In Australia an attempt has been made to overcome the necessity for weighing sticks by measuring fuel moisture content directly by means of a strip of plywood, which bends and straightens as it becomes moister or drier, and is fixed so that it moves as a pointer across a graduated dial; this is described by Higgins (5). By the courtesy of the Forest Products Research Laboratory at Princes Risborough, similar instruments have been made in this country and are now on preliminary trial. At first their behaviour was very erratic, but after some weeks' exposure they settled down and are now giving much more consistent readings. Used in conjunction with some form of correction for wind velocity, state of vegetation, and cumulative drought, they might form the basis of the simplest method yet devised. They are certainly worthy of continued and extended test, preferably in comparison with one of the more established methods.

FORESTERS' FORECASTS.

The six foresters concerned were asked to note each day their opinion of the existing fire danger in one of five degrees, none, slight, moderate, serious, and very serious. Apart from a few guiding remarks, interpretation of these degrees of severity was left very much to the foresters. Thus each forester sent in a monthly record, giving for each day a figure 1, 2, 3, 4, or 5 according to his estimation. An average of these figures was then taken for each day, and used as a basis for comparison with calculated methods. By the time this was started it had been realized that the Fire Danger Index in the Forest of Dean, using the Canadian system, never exceeded 12, and so the maximum danger recorded by the foresters, namely, 5, was regarded as equivalent to 12 on the Canadian scale, and the minimum, namely, 1, as equivalent to 0. Intermediate values were worked out proportionately. So the five degrees of fire danger estimated by the foresters became equivalent to the five degrees of the Meteorological Office system, rather than to those of the Canadian system, the highest of which is seldom, if ever, experienced in this country. It has already been mentioned that foresters' enthusiasm waned after a time, so that from 1943 on, these estimates are based on the opinions of one or two men only.

THE OCCURRENCE OF FIRES.

The Forest of Dean, because it is so thickly populated, because so much of it is common land, and because so many of the inhabitants go to and from work through the woods, is subject to more frequent fires than most forest areas. On the other hand, because of the numerous rides, the easy accessibility, and the scarcity of large blocks of conifer, fires are seldom of large extent. It formed therefore a comparatively good area in which to use the actual occurrence of fires as a check on fire-hazard estimation. On the other hand, so great a human

factor enters into their initiation, that the use of such a check must be very limited. It would certainly be unfair to suggest that a high danger figure was erroneous, just because no fires occurred. On the other hand, there is obviously something wrong with a prediction method, if a serious fire or several fires occur when the danger is rated as low, or if any fire at all occurs when it is negligible. On this rather limited basis the records of fires can be used as an additional comparison.

Data on the occurrence of fires was extracted from the normal forest records, for all fires, however small, have to be recorded. However, for very small fires no acreage need be given, so that the records are incomplete in this detail. For this reason on the graphs fires have had to be shown in two ways, by acreage for the larger fires, and by number for the very small ones, where no figure of area was given.

COMPARISON OF RESULTS.

Naturally it is not possible to give all the records taken over a period of 4 years, and four particularly interesting sections only are reproduced. While these were deliberately selected to illustrate certain points, they are nevertheless reasonably typical of the amount of agreement between the different methods. Each section is considered separately below.

The first, 12th April to 31st May 1941 (Fig. 1), is from the period before the foresters' estimates had been started, and before the Meteorological Office had begun to issue their warnings. So in this case the figures based on their formula were calculated by C. W. Barfoot, using of course actual records, not forecasts. This section illustrates the comparatively smooth curve given by the Canadian, and the terribly erratic curve given by the Meteorological Office method. This tendency to extremes may be somewhat exaggerated by the fact that here we are using the actual calculated values (divided by 1·33), not the danger classes based on them. The very high danger ratings for the three days 26th–28th April were due to a period of moderate winds. The drop on 2nd and 3rd May was due to very slight rainfall, not sufficient, it will be noted, to prevent a small fire on the 3rd. The drop on 15th May was due to two falls of 0·14 and 0·01 inch of rain. In both cases it will be noted that these rainfalls effected the Danger Index on the Canadian system, but to a much lesser degree.

From 4th April to 31st May 1942 (Fig. 2) was a period when estimates from 5 to 6 foresters and the official Meteorological forecasted warnings were available. It will be noted that, on the whole, agreement between the foresters' estimates and the Canadian system is very good, but in April there is a definite tendency for the foresters' estimates to be higher. In our table for calculating the Fire Danger Index from the 'Tracer Index' a lower value was given to the Danger Indices for April than for March, on the assumption that by then there would be some admixture of fresh green with the dead winter dried vegetation; a bigger step down was given to the Danger Indices for the same reason at the beginning of May. In some seasons both these changes might be premature, and considering bracken or heather ground rather than grass, there is probably no justification for making

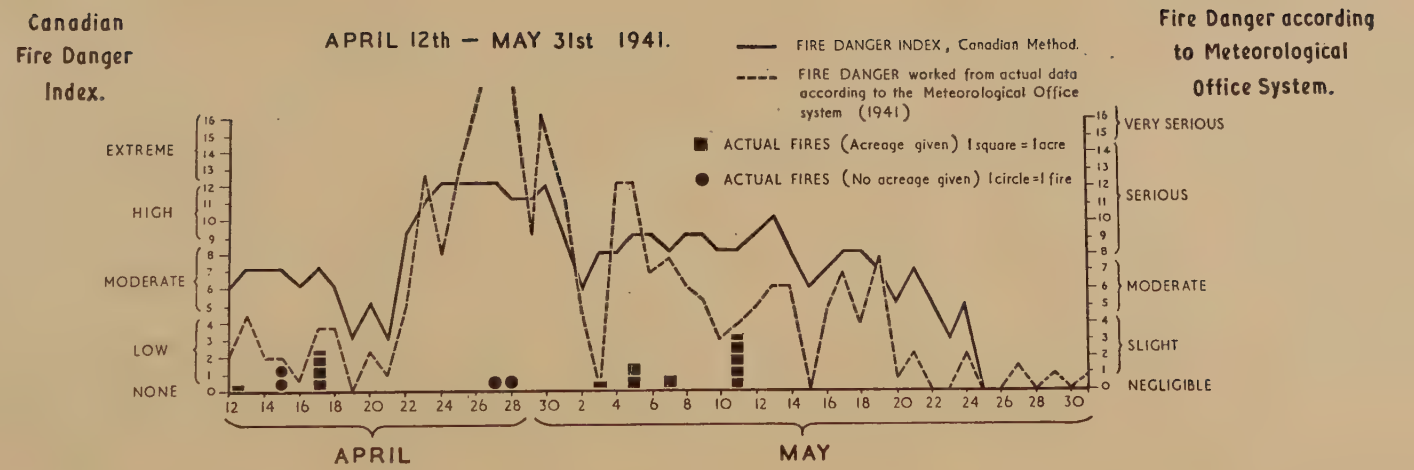

Canadian Fire Danger Index.
APRIL 12th — MAY 31st 1941.
FIRE DANGER INDEX, Canadian Method.
FIRE DANGER worked from actual data according to the Meteorological Office system (1941)
ACTUAL FIRES (Acreage given) 1 square = 1 acre
ACTUAL FIRES (No acreage given) 1 circle = 1 fire
Fire Danger according to Meteorological Office System.
EXTREME
HIGH
MODERATE
LOW
NONE
VERY SERIOUS
SERIOUS
MODERATE
SLIGHT
NEGLIGIBLE
APRIL
MAY

FIG. 1.

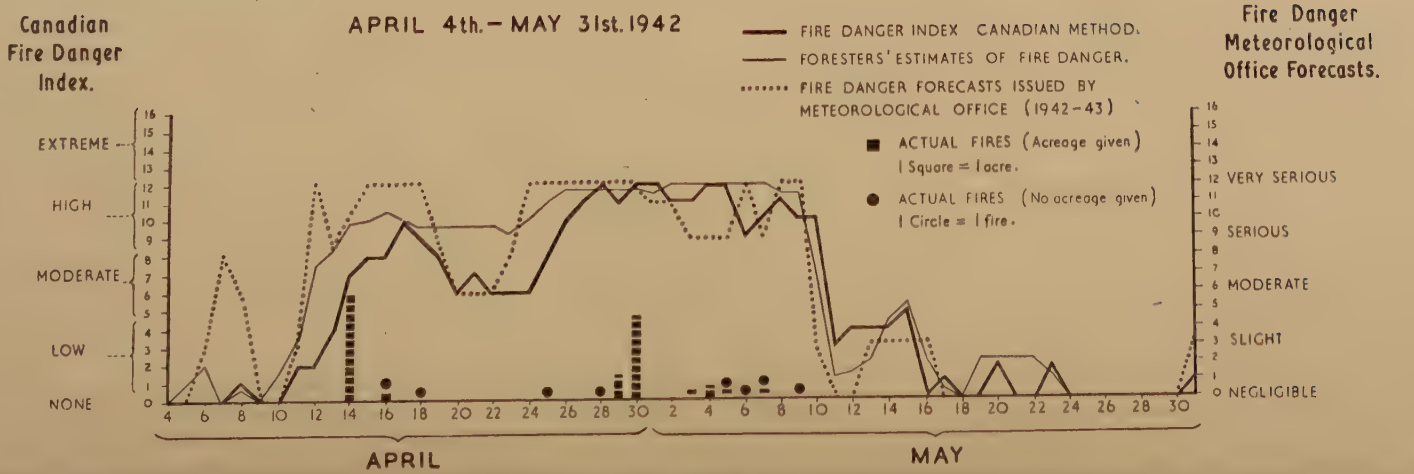

Canadian Fire Danger Index.
APRIL 4th.— MAY 31st. 1942
FIRE DANGER INDEX CANADIAN METHOD.
FORESTERS' ESTIMATES OF FIRE DANGER.
FIRE DANGER FORECASTS ISSUED BY METEOROLOGICAL OFFICE (1942–43)
ACTUAL FIRES (Acreage given) 1 Square = 1 acre.
ACTUAL FIRES (No acreage given) 1 Circle = 1 fire.
Fire Danger Meteorological Office Forecasts.
EXTREME
HIGH
MODERATE
LOW
NONE
VERY SERIOUS
SERIOUS
MODERATE
SLIGHT
NEGLIGIBLE
APRIL
MAY

FIG. 2.

a change at the beginning of April at all, since little fresh growth appears on such areas till May. The April reduction in Danger Indices may account for the rather low values given during April by the Canadian system. The tall fire column on 14th April looks rather startling, considering that on the 9th there was general agreement on a 'Nil' fire danger. It was, however, entirely the result of one 12-acre fire in oak woodland with bracken undergrowth, which would still be highly inflammable at that time of year, and if considered individually, as a separate vegetation type, would undoubtedly qualify for a higher danger index than the average. The fall off in the Meteorological Office graph on the 20th–22nd April was due to a succession of virtually completely calm days. This also affected the Canadian system figure; the calm actually lasted till the 23rd, the weather forecasters presumably expected it to end one day earlier; the Canadian system figure was kept down on the 24th by a shower of rain (0·01 in.), which very naturally was not forecasted, since it was an isolated occurrence in a long dry period, and probably purely local. The foresters appear to have ignored the calm period. The author is inclined to suspect that wind is not considered sufficiently in personal estimates of fire danger, possibly because its effect on rate of spread is not sufficiently realized.

During the third period, 1st April to 11th May 1943 (Fig. 3), only two foresters were still sending in estimates of hazard. As in the spring of 1942, there is a tendency for the Canadian system, possibly owing to our premature introduction of reduction for vegetational changes, to show a lower danger than the foresters. The Meteorological Office were correct in expecting a break in the dry weather on 12th April, though their system attaches too great significance to it. In fact it was limited to a rainfall of 0·01 inch lasting only half an hour, and it is puzzling that the two foresters should have attached such importance to it. The tall fire column on 5th April was due to a single fire, which was in an inaccessible position, and therefore burnt 11 acres before it could be extinguished.

The period 1st June to 11th July 1943 (Fig. 4) is included to illustrate one particular point, the necessity for making some allowance for vegetation. For most of this period the two foresters, and the Canadian system, which during the summer months is subject to a severe reduction factor because of the green state of the vegetation, were in fair agreement, giving at first low and then moderate danger. The Meteorological Office system, under which foresters were expected to make their own vegetation allowances, gives a consistently higher value throughout. The discrepancies at the end of the period between the foresters' estimate and the Canadian system may have been due to local climatic differences. From 5th July only one forester was estimating and he was about 10 miles from the meteorological station in the Forest of Dean, and on a different range of hills. The weather during this period was unsettled, with occasional periods of light rain, and it is perfectly possible that his weather was different to that used as basis for the Canadian system calculations.

In general, therefore, the curves show a very good agreement between the foresters' estimates and the fire danger as recorded by the Canadian system. This agreement could probably be bettered if a more elastic system of vegetational

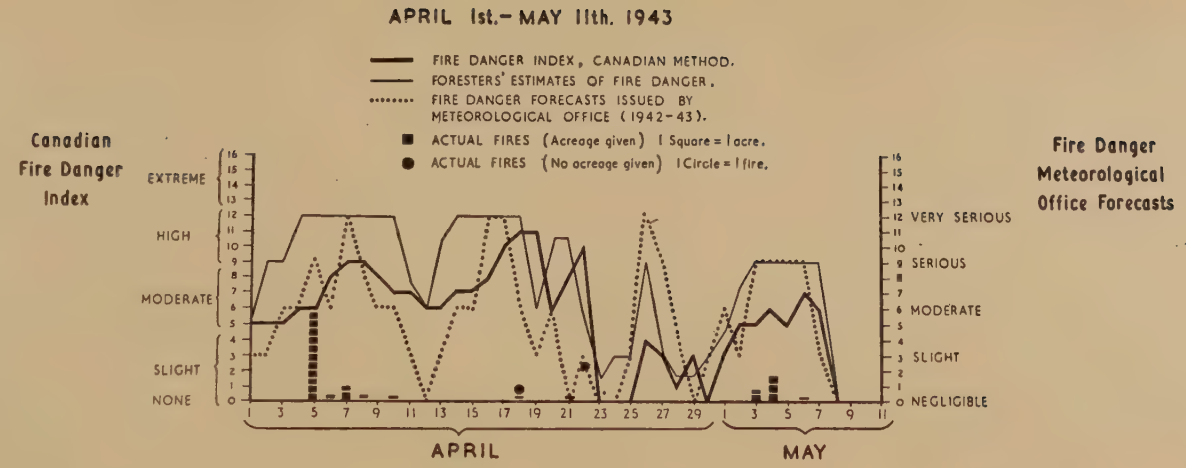

APRIL 1st.– MAY 11th. 1943
FIRE DANGER INDEX, CANADIAN METHOD.
FORESTERS' ESTIMATES OF FIRE DANGER.
FIRE DANGER FORECASTS ISSUED BY METEOROLOGICAL OFFICE (1942–43).
ACTUAL FIRES (Acreage given) 1 Square = 1 acre.
ACTUAL FIRES (No acreage given) 1 Circle = 1 fire.
Canadian Fire Danger Index
EXTREME
HIGH
MODERATE
SLIGHT
NONE
VERY SERIOUS
SERIOUS
MODERATE
SLIGHT
NEGLIGIBLE
Fire Danger Meteorological Office Forecasts
APRIL
MAY

FIG. 3.

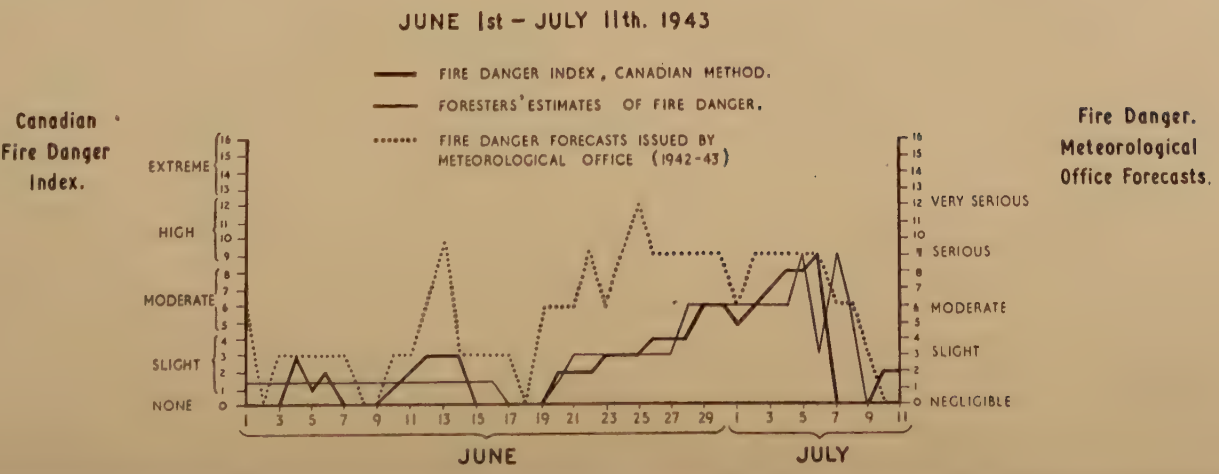

JUNE 1st – JULY 11th. 1943
FIRE DANGER INDEX, CANADIAN METHOD.
FORESTERS' ESTIMATES OF FIRE DANGER.
FIRE DANGER FORECASTS ISSUED BY METEOROLOGICAL OFFICE (1942-43)
Canadian Fire Danger Index.
EXTREME
HIGH
MODERATE
SLIGHT
NONE
VERY SERIOUS
SERIOUS
MODERATE
SLIGHT
NEGLIGIBLE
Fire Danger. Meteorological Office Forecasts.
JUNE
JULY

FIG. 4.

allowances could be introduced. The Meteorological Office system, on the other hand, is seen to be consistently too erratic, and quite obviously it could not be used as a basis for administrative fire precautions.

DISCUSSION.

The results given above indicate that the system of fire-hazard estimation elaborated in Canada by Wright and Beall can be used in this country, and will give in one locality a reasonably smooth curve, agreeing to a reasonable degree with foresters' estimates of hazard, and with the actual occurrence of fires. In the author's opinion the fuel moisture stick method in use over much of the United States could be adapted to give similar results, as probably could the Australian meters, which are still in the experimental stage.

The behaviour of the Meteorological Office scheme, which did not bring fuel moisture or its equivalent into the calculation, is obviously too erratic for practical use. This should act as a warning to those who consider that fire hazard could be dealt with on an even simpler basis, by correlating readings of rainfall, temperature, humidity, &c., over a period with fire hazard, to get a simple formula for future use. It is quite clear that fire hazard cannot be dealt with on the basis of a product formula, simple or complex.

Thus in considering the possibilities of a wider use of fire-hazard forecasting in Great Britain the author has in mind an adapted form of one of the already proven methods, or the possible substitution of the Australian meter for the weighed sticks in the United States system. The most doubtful point is the extent to which more widespread use of fire-hazard estimation would be possible without the provision of additional stations at which it could be calculated. Obviously any system will fall into disrepute unless it satisfies a high degree of accuracy. Inevitably, apart from its accuracy, a calculated hazard would have more influence in the forest of origin than, say, in a forest 10 or 20 miles away. In the author's opinion the extreme variability of the local climate in Great Britain would render it inadvisable for one hazard prediction station to attempt to cover an area of more than 100 square miles in a fairly compact block. Preferably each hazard station should only control *one* fire-precaution area, so that the fire-hazard station and the administrative actions resulting therefrom could all be under one control. In one area the man in charge would know that certain sections of the forest were more or less dangerous at certain times of year than the general block, or that a local thunderstorm had lowered the hazard over part of the forest, and would not regard discrepancies arising from these causes as invalidating the whole system. Thus in the first instance, preferably after further trial, hazard estimation might be used in such compact forest areas as the New Forest, the Forest of Dean, Thetford Chase, or Keilder, or in closely adjacent groups of forests, such as those centring round Rheola in south Wales or the Black Isle group in Scotland.

It may be argued that, since in general the trial of the Canadian system gave results so near to the foresters' estimates, there is no point in using it as well as or in preference to such personal estimates. Several arguments refute this. The

existence of a high calculated hazard might well stimulate the doubtful forester to take precautions which he would otherwise have hesitated to impose, or it might compel the careless to take precautions he would otherwise have forgotten. On the other hand, it might often persuade the over-conscientious forester to relax precautions which were really unnecessary, with a consequent saving of money to his employers and strain to himself. In addition there is the possibility of using calculated fire danger as the basis of public notice-boards to be displayed at the main entrances to the forest, and on which the 'Hazard to-day' would be boldly brought to the notice of the visiting public. Such boards would obviously gain in authority if they were known to be based on calculation, rather than on the whim of the local forest authority. It would be possible to bring them and their scientific basis to the attention of the public through the national and local press.

But if use is to be made of hazard warnings, it is obvious that they must be highly accurate, that their modification in the light of weather changes after they are issued must be the responsibility of one man only, and that they must be taken seriously within the area they cover. This would appear to postulate definitely that they should only cover an area to which they are sure to apply, and which is small enough for the man in charge to beware of the necessity for amendment subsequent to issue. For the same reasons the author is convinced that for this country forecasted hazards would be of little or no value. No local forecasts would be available, and only a meteorological expert would be in a position to adapt the general weather forecasts to local conditions. Any attempt to use the existing Meteorological Office forecasts, based as they are on very wide regions, would be disastrous.

To sum up, therefore, in the author's opinion fire-hazard estimations based on past and present data, not on forecasts, would be of distinct value if applied to limited areas around the station where they were calculated, both as a check on foresters' opinions and as a firm basis for warning notices.

It is of interest to note that over the whole period during which the Canadian system was on trial in the Forest of Dean the Danger Index never exceeded 12, so that the Canadian concept of 'Extreme Hazard' was never reached. This is probably in accordance with the true facts, for in many parts of North America much longer periods of low humidity occur than are ever the case in this country. Certainly nothing is ever experienced in this country comparable with the explosive conditions and extraordinary rates of fire-spread that are occasionally reported from America.

Recent work by Bryan (3) in this country suggests that humidity may be a more potent factor than has been realized in the past. In Wright and Beall's method relative humidity only enters as one of the factors affecting the 'Tracer Index' (fuel moisture content); and in the United States method, although of course it does affect the moisture content of the sticks, it is not used directly in the calculations at all. Bryan has found that atmospheric humidity, apart from its effect on fuel moisture content, directly affects the ease with which wood burns. To quote: 'The effect is most pronounced where continuity of burning is in the balance,

in such cases air humidity may determine whether flaming will continue or not.' A great deal of work would be required before this hitherto neglected factor could be evaluated, but it does suggest the desirability of the introduction of a factor to cover this effect of humidity on the Fire Danger Index, as well as the existing modifications for wind velocity, for region and season, and for cumulative drought. Since the conditioning of the samples and the actual ignition tests were all done at a constant temperature of 25° C., it is not yet known whether the effect is connected with relative or absolute humidity. This being so, it is not yet possible to tell how important this effect will be in practice, since relative humidity, varying as it does inversely with temperature, is a much more changeable factor than absolute humidity which does not vary with temperature. In particular we cannot yet tell whether it has any direct influence on the tendency of fires to occur most frequently in the afternoon, described by Edlin (4). Considering weather factors alone, this tendency might well be covered by the combined effect of the evaporation of dew and the fall in moisture content of the more finely divided fuels, which, owing to their nature, do not lag far behind the daily decline of relative humidity, in their loss of water. Possibly the effect of humidity described by Bryan may be connected with the explosive condition during extreme hazard in America, mentioned above.

SUMMARY.

An account is given of a 4 years' trial in the Forest of Dean of a method of calculating fire danger, based closely on the work of Wright and Beall in Canada. This is compared with a method devised for war-time use by the Meteorological Office, which is also discussed, with foresters' estimates of fire danger, and with the actual occurrence of fires. Brief mention is made of other systems of fire-hazard estimation.

The author concludes that fire-hazard estimation could be applied usefully to small areas of forest for local purposes, but that the English climate is too variable for estimation to be adopted on a wide regional basis.

ACKNOWLEDGEMENTS.

The author has already indicated the extent of his indebtedness to Mr. C. W. Barfoot, and can only add that without his aid the trials would never have got past the initial difficulties. Thanks are due to the Forestry Commission under whose auspices the whole investigation was carried out, and particularly to Mr. W. H. Guillebaud, who gave the author great encouragement in the initial stages. To Mr. H. S. Spenceley fell the unenviable task of carrying on the readings after the author had left the Forest of Dean and after local interest in the venture had waned; it is entirely due to him that the trial covered 4 years instead of 2. Mr. H. W. Beall, then on war service in this country, visited the Forest of Dean, and in discussion then and in writing subsequently gave the author great help and encouragement. To the Director of the Meteorological Office thanks are due for permission to give full details of their method. It is unfortunate that so much of the discussion of this method must needs be critical. Finally thanks are due

to Mr. C. W. Scott and to other members of the staff of the Forest Products Research Laboratory for their assistance in the manufacture of the experimental meters on the Australian pattern.

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PHOTOPERIODISM IN WOODY SPECIES

By P. F. WAREING

INTRODUCTORY.

IT is well known that length of day exerts a decisive effect on the onset of the reproductive phase in many herbaceous plants, and the physiological basis of this 'photoperiodic' response has been the subject of much investigation in recent years (for a review of the subject see R. O. Whyte (24)). It is not so generally realized, however, that the capacity for photoperiodic response appears to be at least as widespread among woody species as among herbs, such processes as the onset of dormancy and leaf-fall being controlled in many trees by natural changes in day-length. Although our knowledge of photoperiodism in trees is not yet so complete as it is for herbaceous plants, it is already clear that variation in day-length is an important factor in the annual cycle of growth in woody species, and that many species show a delicate adjustment to the day-length conditions of their natural habitat.

It is thus clear that photoperiodism has an important bearing on various problems associated with forestry, and it is hoped therefore that the following review will serve to make the subject better known.

EFFECT OF DAY-LENGTH ON THE DURATION OF GROWTH.

As long ago as 1914, Klebs (10) reported that under conditions of continuous artificial illumination, beech (*Fagus sylvatica* L.) could be induced to break dormancy in September and under such conditions could be kept growing continuously throughout the winter. Similarly, Garner and Allard (5) found that plants of *Liriodendron tulipifera* L. transferred to a greenhouse in September and exposed to normal daylight supplemented by electric light until midnight promptly renewed active growth and remained growing continuously for 18 months, whereas plants under similar conditions, but without additional illumination to prolong the natural day-length, remained dormant throughout the winter. These workers also found that under a 10-hour photoperiod[1] growth of seedlings of *Acer negundo* L. in the summer was very small as compared with that under normal summer day-lengths. On the other hand, grafts of apple (*Malus pumilla* Mill.) exposed to short days (12-hour) made more rapid growth than similar grafts exposed to normal day-length.

Experiments on the effect of day-length on seedlings of a wide variety of woody species were carried out independently by Bogdanov (2, 6) and Moshkov (17, 18) in the region of Leningrad. Several species of the following genera were used: *Acer*, *Aesculus*, *Ailanthus*, *Alnus*, *Caragana*, *Corylus*, *Fraxinus*, *Juglans*, *Larix*, *Phellodendron*, *Pinus*, *Prunus*, *Pyrus*, *Rhus*, *Robinia*, *Salix*, and *Ulmus*. The plants were grown either under the full summer day-length or under various shorter

[1] The term 'photoperiod' is applied to the daily period of exposure to light.

photoperiods down to 9 hours, obtained by covering the plants with light-proof covers for appropriate periods. It was found that with the majority of species short days hastened the onset of dormancy as indicated by earlier cessation of extension growth and earlier leaf-fall. For example, Moshkov found that under the natural Leningrad day, *Robinia pseudacacia* L. had not completed its growth after 5 months, so that the young growing-tips were destroyed by the autumn frosts; but with photoperiods of 14 and 10 hours the growing period was reduced to 2½ months and 1 month, respectively. With the earlier onset of dormancy the annual growth made by the plants was correspondingly less, and the frost-resistance of such plants was considerably greater than that of plants of the same species grown under the natural Leningrad day-length. In the case of *Salix babylonica* L. and *Pyrus ussuriensis* Maxim. it was found that the duration of the growing period and the height attained by the plants was greater under a 14-hour day than under the longer photoperiods of the natural day. With these species, therefore, it appears that there is an optimum photoperiod for maximum growth of the shoot, whereas with the other species the greatest growth was obtained with the longest days.

Results in agreement with those described above have been obtained by Kramer (11) with seedlings of various North American species, including *Fraxinus* spp., *Fagus grandifolia* Ehrh., *Robinia pseudacacia* L., *Liriodendron tulipifera* L., *Liquidambar styraciflua* L., *Quercus* spp., and *Pinus taeda* L. It was found that dormancy was hastened by short days in all species except *Quercus alba* L., and that long days delayed dormancy in the majority of species, as compared with normal day-lengths. *Robinia pseudacacia* L., *Liriodendron tulipifera* L., and *Pinus taeda* L. could be maintained in growth throughout the winter under long days or continuous illumination. The growing periods of the two species of *Fraxinus* and *Quercus borealis* var. *maxima* Sarg., however, were not affected by long days. Similar results were obtained by Jester and Kramer (9).

From the above experiments, which cover a considerable number of species belonging to a wide variety of genera, it may be taken as well established that dormancy is hastened by short days in *seedlings* of the majority of woody species and delayed by long days. Indeed, with some species, when the day-length exceeds a certain 'critical' value growth may be maintained continuously throughout the winter. At day-lengths below this 'critical' daily photoperiod the duration of the growing period increases as the length of the daily photoperiod increases (17, 18). That is to say, for any given constant daily photoperiod the annual shoot is able to attain a certain stage of development and then growth ceases with the formation of a terminal resting-bud. The (unpublished) results of experiments carried out by the writer with first-year seedlings of Scots pine (*Pinus sylvestris* L.) indicate that under any given cultural conditions there is for each value of photoperiod a certain mean number of leaves developed before the terminal bud is formed. It is not clear whether the attainment of a certain specific number of leaves is itself the factor controlling the cessation of growth, or whether leaf number is merely correlated with certain 'internal' factors controlling development. The observation that artificial defoliation may prolong the duration of growth (1, 16, 22) is,

however, apparently evidence in support of the former alternative. From the data already considered it is evident that there is a 'specific leaf number' corresponding to each day-length below the 'critical' photoperiod. This idea of 'specific leaf number' corresponds with the concept of 'minimum leaf number' used by Gregory and Purvis (7) as an index of 'ripeness-to-flower' in annual plants.

Woody species do not readily fit into the classification of 'short-day' and 'long-day' species generally accepted for the photoperiodic induction of flowering in herbs, for most woody species (whether adapted to regions of relatively short natural day-length or of long day-length) resemble most closely the short-day type of annual plant in that the duration of the vegetative growing period in both groups is reduced by short days and prolonged by long days, and may even be continuous under very long photoperiods.

It is characteristic of photoperiodism in herbaceous plants that the responses are fully evoked by quite low light-intensities, which can have no appreciable effect on assimilation. This is also true of photoperiodic effects in woody species, intensities as low as 1 foot-candle apparently being effective for some species (12, 15).

PHOTOPERIODISM AND THE ANNUAL GROWTH CYCLE.

The facts described above suggest that length of day may play a part in determining the duration of the growth period of woody species in nature. Because, in general, short days promote early incidence of dormancy, it is clear that the falling day-length in the autumn will ultimately bring about cessation of growth in any shoots still active at that time.

Not all woody species normally remain in active growth until there has been any appreciable fall in the natural length of day, however, many species from northern latitudes completing their annual extension growth by May, June, or July (4, 13). Klebs (10) made observations on the length of the growing season in 165 woody species growing at Heidelberg, and found that they formed a continuous range from those which ceased growth in May to those which continued active growth until 'well into the autumn' (October). He found, however, that the duration of growth depends upon the age of the tree, the position of the shoot, and the cultural conditions. Young trees and young shoots arising directly from the base or main trunk frequently cease growth much later than the tips of the main branches of an older tree.[1] Hence the natural day-length conditions during the period of extension growth will be different according as to whether we are considering younger or older trees.

If we classify woody species according to the duration of the growing period in relation to the natural day-length, we may recognize three main groups:

1. Species in which growth remains continuously active until September or October, when the natural day-length is very much shorter than during the summer months. This group includes many shrubs and woody climbers, together

[1] Burger (3), on the other hand, found that the period of extension in some trees increases with age.

with the young stages of many larger trees, e.g. [1]*Viburnum opulus* L., *Cornus sanguinea* L., *Forsythia viridissima* Lindl., *Ligustrum vulgare* L., *Rhus* spp., *Prunus laurocerasus* L., *Vitis vinifera* L., *Clematis vitalba* L., *Lonicera periclymenum* L., *Hedera helix* L., *Salix* spp.; also the young stages of *Sambucus nigra* L., *Robinia pseudacacia* L., *Alnus glutinosa* Gaertn., *Chaemacyparis lawsoniana* Parl., and other species of which the older stages are appropriate to the second group.

With these species there is every indication that reduced day-length in the autumn ultimately determines the cessation of growth, for if, for example, young plants of *Robinia pseudacacia* L. growing out of doors are given supplemented illumination to extend the natural day in the autumn, the growing period is prolonged (12) and ultimately growth ceases owing to the unfavourable temperature conditions. It seems probable that the natural day-lengths during the summer exceed the 'critical' value for these species, which continue growth indefinitely under photoperiods equal to those of midsummer.

2. Species in which growth ceases in July or August, when day-length conditions have not changed appreciably from those prevailing during the early stages of growth in April and May. This group includes *Alnus glutinosa* Gaertn., *Carpinus betulus* L., *Betula* spp., *Picea abies* Karst., *Larix decidua* Mill., *Pseudotsuga taxifolia* Brit., *Platanus orientalis* L., *Robinia pseudacacia* L., *Liriodendron tulipifera* L., *Ailanthus altissima* Swingle, and the young stages of *Acer pseudoplatanus* L.

As we have already seen, studies of the duration of growth at *constant* day-length show that for every species there is a certain maximum amount of growth (as indicated by the leaf number) possible at any given photoperiod. It would appear, therefore, that species of this second group cease growth in July and August because by then they have attained the specific leaf number corresponding to the day-length then prevailing. That is to say, in contrast to the species of the first group, with these species even the maximum summer day-lengths do not exceed their 'critical photoperiods'. If this interpretation is correct, the problems involved in the determination of dormancy are not fundamentally different in the two groups.

3. Species in which growth ceases in May or June. In many, and probably all, these species the annual growth of the shoot is limited to expansion of the initials already laid down in the bud, and no new leaves are formed which were not already present in the bud (4). This group includes many of the trees endemic to northern Europe, e.g. mature trees of *Fagus sylvatica* L., *Quercus petraea* Liebl., *Aesculus hippocastanum* L., *Juglans regia* L., *Fraxinus excelsior* L., *Rhamnus cathartica* L., *Pyrus communis* L., *Sorbus aucuparia* L., *Acer pseudo-platanus* L., *Pinus sylvestris* L., *Pinus nigra* Arnold, and *Abies* spp.

[1] The majority of these examples are taken from the observations of Klebs (10) at Heidelberg (Germany) and of Burger (3) at certain localities in Switzerland. Corresponding data for species growing in Great Britain do not appear to be readily available, and although the writer has confirmed that many of these continental observations are applicable also for southern England, the assignment of the various species to particular groups must be regarded as subject to confirmation.

In some of these species, e.g. *Pinus sylvestris* L. (4, 25), the leaf initials are laid down *two* years before the unfolding, so that within the obvious resting-bud the minute resting-bud of the following year is already formed. In all those species in which the total number of nodes or leaves of the annual shoots is predetermined in the bud it is clear that the duration of growth is affected, not by the external conditions during the expansion of the bud, but by those prevailing in the previous year, when the shoot primordia are being laid down (4).

In these species in which the amount of the annual growth is predetermined in the bud, it must be supposed that the actual number of leaf initials laid down corresponds approximately with the 'specific leaf number' for the prevailing summer day-length conditions. There is, however, as Klebs pointed out, a tendency in these species to the production of a second crop of 'Lammas'-shoots under certain conditions. This is particularly true of young trees, where instead of the prolonged continuous growing-period found in young trees of the first two groups, additional growth is effected by the production of 'Lammas'-shoots; in older trees of this type the majority of shoots have only one period of extension each year. If the day-length conditions are abnormally long, the tendency to the production of 'Lammas'-shoots is still further enhanced. Thus Bogdanov (2) found that species of *Pinus* from south Russia produced 'Lammas'-shoots when grown under the longer days of Leningrad, whereas normally there is only one annual period of extension growth. Gustafson (8) obtained similar results in *Pinus resinosa* Ait., with a 16-hour day as compared with only one period of growth under the shorter natural day-length, while Phillips (20) was able to induce premature breaking of dormancy in December in plants of *Pinus taeda* L. exposed to an 18-hour day. Similarly, Klebs (10) obtained three successive periods of shoot elongation in beech exposed to continuous illumination in winter. These observations afford a partial explanation as to why 'Lammas'-shoots are most liable to occur during the height of summer, when the natural day-length is greatest.

Although the above classification of woody species is a convenient one in considering the duration of the growth period, it will be realized that each category probably intergrades into the next, and indeed in certain species the young stages may pass from the 'Group 1' to the 'Group 2', or from the 'Group 2' to the 'Group 3' type of growth, as they attain maturity. Moreover, other environmental conditions, particularly soil moisture and nutrient supply, have an important effect, the growing period being longer under favourable conditions than under unfavourable (10).

The biological advantage of the photoperiodic reaction in those species whose growth continues well into the autumn is easily understood, for it appears to provide a means whereby the dormant condition is attained before the severe conditions of winter set in. Young growing shoots are well known to be much more susceptible to frost damage than dormant shoots. Hence a species of the 'Group 1' type grown in a latitude where the natural day is longer than that of the normal region of growth will be liable to frost damage in the autumn. Thus Moshkov (17) found that under the natural day-lengths of Leningrad, *Robinia pseudacacia* L. continued growing until it was damaged by autumn frosts, whereas

under short days in the same region it became dormant sooner and was then frost-resistant. Kramer (12) kept two series of plants of *Abelia grandiflora* Rehd. out of doors in the autumn, and exposed one series to normal day, while the other received additional illumination to give a photoperiod of 14½ hours. Very little further growth was made by the plants under normal day, and they proved frost-resistant, whereas the plants under long days produced succulent new growth which was destroyed by frost. Thus the effect of day-length on the duration of the growth period has an important bearing on the problem of frost-damage in those species which continue growth late into the autumn (19).

The same significance, however, does not appear to be applicable to the species of the second and third groups, in which extension growth of the shoot ceases long before the advent of the autumn frosts. It must be remembered, however, that dormancy in the full sense involves not only cessation of extension growth but also leaf-fall (in deciduous species), dormancy of the cambium, and certain physiological changes in the tissues as yet little understood.

Now it is known that the time of leaf-fall is indeed controlled by day-length in many species. Thus Garner and Allard (5) brought plants of *Rhus glabra* L., *R. copallina* L., and *Liriodendron tulipifera* L. into the greenhouse in September and provided half the plants with additional artificial illumination until midnight, while the remainder received no additional illumination. The plants of *Rhus glabra* L. and *Liriodendron tulipifera* L. receiving additional illumination retained their leaves all winter, whereas the control plants lost their leaves just as soon as those growing out of doors. In the case of *Rhus copallina* L. the long-day conditions delayed leaf-fall for several weeks, but not indefinitely. Experiments by other workers have given similar results, and it has been shown (15) that illumination of intensity as low as 1 foot-candle from street lights may delay leaf-fall in the autumn. Inasmuch as leaf-fall is associated with dormancy of the cambium and generally increased resistance to unfavourable conditions, it is clear that the time of its incidence in relation to the onset of winter conditions must play an important part in the adaptation of a species to any given region.

This possibility, however, is not applicable to those species of the second and third groups which are *evergreen*. The best examples of this category are seen in the evergreen conifers, e.g. *Pinus* spp. Geographical races have long been known in *Pinus sylvestris* L., and in a number of experiments in which races from northern latitudes have been grown in more southern regions it was found that such races showed reduced growth in height and reduction of needle-length as compared with the growth attained in more northern regions (see Sylven (23) for references). Sylven suggested that this might be a photoperiodic effect, resulting from the reduced day-length at lower latitudes. The experiments of the writer (unpublished) have established that *P. sylvestris* L. is indeed photoperiodic, and that first-year seedlings respond to short days by hastened dormancy and also by a reduction in internode length and leaf-length. After the first year of growth, however, the duration of extension growth is unaffected by day-length since in *P. sylvestris* L. the number of 'dwarf shoots' is predetermined in the bud, and elongation of the shoot ceases in June, when full expansion of the stem initials

laid down in the buds has occurred. The leaf, however, continues growing for a much longer period by means of a meristem at its base, and it is found that the duration of growth of the needles is affected by day-length so that under reduced photoperiods they cease growth much sooner than normally. It is difficult to see what biological advantage accrues to the tree from photoperiodic control of the duration of needle-growth, and it seems possible that this is only a secondary effect arising from photoperiodic control of a more fundamental process which has so far escaped observation.

We have thus evidence of at least three processes affected by day-length in different woody species, viz. (1) duration of extension growth, (2) time of leaf-abscission in deciduous species, and (3) duration of leaf-growth in certain evergreen conifers. It seems probable that as our knowledge of photoperiodism in woody species is extended, yet other processes will prove to be affected by day-length. Indeed Langlet (14) has reported that northern strains of *P. sylvestris* L. grown under the shorter days of more southern latitudes first show female reproductive organs at an earlier age than is the case in their normal region of growth. Hence there is indirect evidence that day-length may affect the initiation of the reproductive phase in woody species, as in herbaceous plants. In this connexion the suggestion of Garner and Allard (5) that the reduced vegetative growth of apple during long summer days may favour the formation of fruit buds is of interest.

EFFECT OF DAY-LENGTH ON BREAKING OF DORMANCY.

The experiments of Klebs (10) on the effect of continuous illumination of beech (*Fagus sylvatica* L.) seedlings in the winter showed that whereas all efforts to break dormancy by methods which are successful with many other species (e.g. hot-water treatment, ethylene, &c.) are ineffective with beech, a period of exposure to continuous artificial illumination at 1,000 foot-candles rapidly brings about unfolding of the buds, even when the plants are in the leafless winter condition. Provided the shoots receive the necessary preliminary period of illumination, their subsequent unfolding can take place equally well in the light or dark. Klebs examined the effect of the length of the daily period of illumination on the breaking of dormancy and obtained no difference whether he used a 12-hour or an 18-hour day, and he came to the conclusion that the *quantity* of light received (intensity × time) was the determining factor. As the phenomenon of photoperiodism had not been discovered at the time of Klebs's experiments, however, it is possible that he too easily dismissed any possible effect of length of day. However, Garner and Allard (5) found that a number of small trees and shrubs, including *Acer negundo* L., *Acer rubrum* L., *Cornus florida* L., and *Rhus glabra* L., which were exposed to an 8-hour day beginning early in January, successfully unfolded their leaves at about the same time as did the 'controls' exposed to normal day. Kramer (11), on the other hand, found that breaking of dormancy of leafless seedlings of various species brought indoors in January was hastened under long days, but nevertheless ultimately occurred also under short days. Kramer found, however, that seedlings of woody species kept *out of doors* in the

spring ultimately broke dormancy at the same time in April, whether under long or normal days, and concluded that, normally, by the date when temperature has risen sufficiently to permit growth, the length of the natural day is no longer a limiting factor.

It would appear, therefore, that while some species, such as beech, require a minimum period of illumination before breaking of dormancy can occur, there is no evidence that in any species the length of day normally controls the time of unfolding of the buds in the spring, and probably in the majority of species the seasonal rise in temperature is the determining factor. The premature breaking of buds in the production of 'Lammas'-shoots in the summer by abnormally long days seems to be a distinct phenomenon and to have no relevance to the question at present under discussion. It is well known, on the other hand, that the breaking of dormancy in the spring is in many species dependent upon a previous exposure to low temperatures during the winter. An interesting case is reported by Gustafson (8), who found that plants of *Pinus resinosa* Ait. which had been allowed to remain out of doors during the winter broke dormancy in the normal way under natural day-length conditions in the spring, but plants which had been protected from low temperatures during the winter showed no new shoot growth under natural spring day-lengths, but did so if the photoperiod was increased to 16 hours. It was thus possible to achieve the breaking of dormancy by exposure either to low temperatures or to long days.

PRACTICAL IMPLICATIONS OF PHOTOPERIODISM.

While it does not seem feasible as yet to apply artificially shortened or lengthened photoperiods in manipulation of the growth of woody species for economic purposes (as is the practice with certain horticultural crops), the possibility that this may one day be practicable is by no means excluded, particularly in nursery work. Nevertheless, knowledge of the phenomena of photoperiodism is not without present value to the forester, as, of course, is the case with all advances which increase his understanding of the growth-processes in woody species. It is now evident that the adaptation of a species to the climatic conditions of any given geographical region will usually include adjustment to the natural day-lengths of that region, as well as to other factors such as temperature, rainfall, &c., which have long been recognized as important. This fact must be borne in mind when considering the introduction of new species into any region. It was pointed out above that some species from southern latitudes grown in more northerly regions tend, because of the longer natural photoperiods, to continue growing longer than in their region of origin, and thereby become liable to damage by frost. On the other hand, species indigenous to northern latitudes must be expected to show reduced growth in more southern regions.

Moreover, not only do differences exist between species with respect to their photoperiodic responses, but within certain species having a wide geographical range we find the existence of distinct races differing from each other with respect to their day-length requirements. Reference has already been made to evidence for the view that geographical races within *Pinus sylvestris* L. differ in respect

of their photoperiodic responses. Similarly Sylven (23) has shown that within the species *Populus tremula* L. the races from northern Sweden differ in their photoperiodic responses from those of southern Sweden, and that when northern strains are growing in the south they show reduced growth and stunting, while southern strains grown in the north show delayed dormancy and are damaged by autumn frosts. Local races differing with respect to the length of the growing period are known for a considerable number of other species (3, 4), and there seems little doubt that further study will reveal genetic differences between such races with respect to photoperiodic response. It is thus evident that photoperiodism is of great importance in relation to problems of provenance.

The question naturally arises as to the order of latitude-difference at which differences in natural day-length become important. For example, it may be asked whether the difference in natural day-length between southern England and Scotland is sufficiently great to cause a differentiation of geographical races with respect to photoperiodic response. Obviously no satisfactory answer can be given to this question in the present state of our knowledge, and it may be anticipated that each species will behave differently in this respect. It is of interest to note, however, that strains of *Populus tremula* L. from various localities in Sweden differing in latitude by 2–3° showed genetic differences with respect to photoperiodic response.

Differences in the effective day-length may arise not only directly from differences in latitude, however, but also indirectly from differences in spring temperature, which affect the time of unfolding of the buds. Where the buds unfold early in the season the natural day-length will be appreciably shorter than for those buds which unfold later. Thus a delay of 4 weeks in the breaking of dormancy from 1st April to 1st May in the latitudes of southern England will mean a difference in day-length of nearly 2 hours. This may have an important effect on those species in which the annual extension growth is completed in 6–8 weeks, which is the case with a number of trees. The chief causes of differences in spring temperature will be altitude and latitude. Thus Romell (21) observed differences in the time of commencement of growth in *Pinus sylvestris* L. due to differences in altitude and latitude. Hence local races from different altitudes may be expected to show differences in respect of photoperiodic response, even though the latitude may be constant. Similarly the fall in mean temperature generally associated with increased latitude will result in the growth of the annual shoots commencing later, and hence under longer day-length conditions, and this effect will augment the direct effect of increased day-length at higher latitudes.

Finally, reference may be made to the implications of photoperiodism for any breeding programme. In breeding for improved types, a knowledge of the effect of day-length on the duration of the growth period is obviously of great importance, for new types must show the same delicate adjustment to day-length as is found in nature.

SUMMARY.

The capacity for photoperiodic response has been shown to be present in a wide variety of woody species. In seedlings grown under experimental conditions the length of day affects the period of growth of the shoot, the time of leaf-fall in many deciduous species, and the period of growth of the leaves in certain evergreen conifers.

The effect of natural seasonal changes in day-length on the annual cycle of growth is discussed. Many species show a delicate adjustment to the natural day-lengths of their normal region of growth.

Photoperiodism has important implications for certain matters associated with forestry, such as frost resistance, problems of provenance, and the breeding of new types.

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VARIATION IN TRACHEID LENGTH FROM THE PITH OUTWARDS IN THE WOOD OF THE GENUS *LARIX*

WITH A NOTE ON VARIATION IN OTHER ANATOMICAL FEATURES[1]

By SHIH-CHEN LIANG

(*Forestry Department, University of Aberdeen*)

INTRODUCTION.

THE wood of coniferous trees is built mainly of longitudinal tracheids. The length of these tracheids varies from one part of the stem to another; from the pith outwards at the same height, from the top of the trees downwards in the same ring, &c. On the variation from the pith outwards, Sanio (12) stated 'In the stem (and branches) the tracheids show an increase in size from within outwards, throughout a number of annual rings, until a certain size is reached, which then remains constant in subsequent years.' This statement is known as one of Sanio's five laws governing the variation in size of the tracheids in conifers. The second part of this law, that '. . . until a certain size is reached, which then remains constant in subsequent years', has not been accepted as conclusive. Except for Kribs (9), who found a constant tracheid length in seven Jack Pine trees, no investigator found such a constant in any other coniferous species. For instance, Bailey and Tupper (3) commented: 'Inasmuch as Sanio found a constant in all cases within the 50th ring, and in one case within the 20th, Shepard and Bailey (13), and subsequently Gerry (7), and Lee and Smith (10), found no such constancy. Their observations have shown that in *Pinus strobus* L., *P. palustris* Mill., *Picea rubra* Link., *Pseudotsuga taxifolia* Brit., *Tsuga canadensis* Carr., and *Abies concolor* Lindl. and Gord., the tracheids were found to increase rapidly in length from the pith for a period of years, varying from 20 to 60; but no constant length was attained even in trees several hundred years old. Following the first period of rapid increase in length, the size of tracheids fluctuated more or less during the subsequent growth of the stem.'

The present article presents data on this subject for the genus *Larix*. An attempt is also made to trace the causes of the variation in question. Since Chalk (5) inferred that 'all types of variations in tracheid length, namely, (1) outwards at the same level, (2) upwards in the same ring, and (3) upwards at the same number of rings from the pith, may be the same phenomenon measured in different ways', the explanation suggested in this article may provide a basis for further investigation of this phenomenon.

[1] Based on a thesis for the degree of Ph.D., of the University of Aberdeen, entitled 'The Study of Wood Anatomy within the Genus *Larix*, and the Influence of Internal and External Factors thereon.'

MATERIAL AND METHODS.

The material consisted of three trees of the genus *Larix*, namely, one European larch (*Larix decidua* Mill., Tree No. EL 2), one Japanese larch (*L. leptolepis* Gord., Tree No. JL 7), and one hybrid larch (*L. eurolepis* Henry, Tree No. HL 8). The latter species is the hybrid of the former two species. These three trees were obtained from the Atholl Estates, Dunkeld, Perthshire, in October 1946. They were about 40 years old, and were all growing in stands of normal density, and were of average size for their respective stands.

The basal disks (1 foot above the ground) of the stem of these three trees were used. The disk numbers are EL 21, JL 71, and HL 81. Along the northern and southern radii of EL 21 and JL 71, and along the northern, western, and southern radii of HL 81, small pieces of wood, each consisting of two annual rings, were extracted successively from near the pith outwards until the last layer of the 1945 year ring was reached. It was noticed that there was a knot along the middle part of the northern radius of the disk HL 81. This knot may have affected the tracheid length there.

The samples of wood were macerated by Schultze's method. The separated tracheids were stained with safranin, and were put on a slide for observation. A Leitz micro projector was used for this purpose. This apparatus was clamped in a vertical position, so that the image was projected downwards on to a horizontal screen. A magnification of 50 diameters was used. The measurements were done with a scaled plate. From each sample 50 tracheids were selected at random and their lengths measured, without paying special attention to whether the tracheid was from the early—or from the late—wood.

DATA AND THEIR ANALYSIS.

The average tracheid length of the fifty measurements of each sample, together with its associated data, are listed in Table I.

Column 2 of Table I shows the number of rings counted from the pith to the outer layer of the given ring. This 'ring number' was also regarded as an index of the age of the tree. Column 3 shows the length of radius from the pith to the outer layer of the given ring. When two radii were compared with an interval of 2 rings between them, the shorter one was denoted as r_1, and the longer one r_2. Column 4 gives the total width of each pair of rings, and the difference between r_2 and r_1. Column 5 gives the value of the ratio r_2/r_1. When the value of this ratio decreased from an inner to an outer position, the value at the outer position was marked with a bar (−); when it increased, the value of the outer position was marked with a cross (+). Column 6 gives the average tracheid length of every two rings based on 50 measurements.

The data listed in the sixth column show that the tracheid length increased from near the pith, along a given radius, outwards, at first rapidly, then slowly, and then it fluctuated. This pattern agrees with the statement given by Bailey and Tupper (3).

Harlow (8), Kribs (9), and Bethel (4) suggested a correlation between tracheid length and the age of the tree. According to their results, the greater the number

of rings counted from the pith, the longer would be the tracheid length. This may be partly true, as the tracheid length increases from the pith outwards for a number of years. But as soon as the tracheid length begins to fluctuate, the tracheid-length/age curve is no longer smooth; and if the tree is old enough, the correlation in question is not significant. Other workers (13) attempted to establish a relationship between tracheid length and ring width but failed. Neither could a direct correlation between tracheid length and ring width be found in this study, because, as shown in columns 4 and 6, both variates fluctuated along the given radii, but not markedly in relation to each other. It is noted that Chalk (5) found a negative correlation between tracheid length and ring width; his measurements were not taken from the pith outwards, however, but were at various aspects of the same ring, at the same height.

As tracheid length did not vary clearly with age of tree (number of ring from the pith) or ring width, the problem was to discover the independent variate with which tracheid length varies. The comparison between the data in columns 5 and 6 showed that every increase in the ratio r_2/r_1 corresponded with a decrease in tracheid length, and vice versa. There were so few exceptions that it appeared likely that this was not due to chance. Thus it might be expected that the quantity of variation in tracheid length (i.e. dependent variate) was dependent on the quantity of variation in the ratio r_2/r_1 (i.e. independent variate). This relationship might be expressed by a regression equation, and its significance might be tested by the analysis of variance (6). It was the aim, also, to determine which of the two relationships, namely, 'the tracheid-length ring-number' or 'the tracheid-length ratio-r_2/r_1 connexion', was the essential one. Therefore 'ring number' was also taken into account as an independent variate. The following regression equation was devised:

$$y = a + b_1 x + b_2 z,$$

where

y = tracheid length in mm,
x = rectified 'ratio r_2/r_1', namely, log(100 log r_2/r_1),
z = rectified 'number of rings from the pith', namely, log(ring number),
a, b_1, and b_2 = regression coefficients.

Data of the ratio r_2/r_1 and data of ring number were rectified to make the y-on-x and y-on-z curves linear. Based on the data in Table I, the above regression equation was fitted to seven sets of measurements. Thus:

(1) EL 21 S : $y = 1{\cdot}661 - 0{\cdot}728x + 0{\cdot}778z$
(2) EL 21 N : $y = 1{\cdot}476 - 0{\cdot}679x + 0{\cdot}867z$
(3) JL 71 S : $y = 2{\cdot}880 - 0{\cdot}724x - 0{\cdot}070z$
(4) JL 71 N : $y = 2{\cdot}937 - 0{\cdot}623x - 0{\cdot}162z$
(5) HL 81 S : $y = 1{\cdot}500 - 0{\cdot}505x + 0{\cdot}696z$
(6) HL 81 N : $y = 0{\cdot}924 - 0{\cdot}245x + 1{\cdot}098z$
(7) HL 81 W : $y = 2{\cdot}006 - 0{\cdot}629x + 0{\cdot}417z$

The significance of regression of these seven sets was tested by the analysis of variance. The results are listed in Table II.

Table II shows that

1. Either the combined effect of the independent variates, namely, the ratio r_2/r_1, (x) and the ring number (z) (see item A in the table), or the effect of one of these two independent variates alone (items B and C), upon the variation in tracheid length, was highly significant.

2. A comparison between items B and C showed that the effect of the ratio r_2/r_1 alone upon tracheid length was always greater than that of age alone, except in the case of the samples from the northern radius of the section HL 81 (shortly HL 81 N).

3. Item D showed that the variability of the tracheid length was accounted for by the independent variate, age of the tree, when the ratio r_2/r_1 had already been taken into account, but was not significant except in the case of HL 81 N.

4. Item E showed that variability in tracheid length was accounted for by the independent variate, the ratio r_2/r_1, when age of the tree had already been taken into account, and was significant in all cases except that of HL 81 N and HL 81 S.

The exceptional case of HL 81 N was due to the knot referred to on p. 223. The wood produced there under the influence of the knot shortened the average tracheid lengths for several years, and thus obscured the normal relation of the ratio r_2/r_1 to tracheid length.

Therefore, in the case of the normal clean stem wood, if the age of the tree is used as the factor to predict the tracheid length, a significantly improved prediction will be obtained by taking the ratio r_2/r_1 into account. If the ratio r_2/r_1 is used as the factor to predict the tracheid length, the improvement in prediction as a result of taking the age of the tree into account as well will not be significant. In other words, the relationship between tracheid length and the ratio r_2/r_1 is closer than the relationship between tracheid length and the age of the tree.

The regression equations of y on x and z, as well as y on x, were fitted to each of these three disks and to the three disks combined. The significance of the different regressions between disks and within disks was tested by the analysis of variance. The results are shown in Tables III and IV.

Both Table III (regression of y on x and z) and Table IV (regression of y on x alone) show that

1. From Item B, differences between three regressions of three disks were highly significant. The variances due to these differences were further analysed

   (i) From Item B_1, the difference between two regressions of disks EL 21 and JL 71 was highly significant.

TABLE I. *Average Tracheid Lengths and their Associated Data*

(Average based on 50 measurements in each case)

		Along the southern radius				*Along the northern radius*				*Along the western radius*			
1	2	3	4	5	6	3	4	5	6	3	4	5	6
Disk no.	*Ring no. from the pith*	*Radius from pith (cm.)*	*Σ ring widths of 2 rings (cm.)*	*Ratio r_2/r_1*	*Tracheid length (mm.)*	*Radius from pith (cm.)*	*Σ ring widths of 2 rings (cm.)*	*Ratio r_2/r_1*	*Tracheid length (mm.)*	*Radius from pith (cm.)*	*Σ ring widths of 2 rings (cm.)*	*Ratio r_2/r_1*	*Tracheid length (mm.)*
EL 21	4	0·95	..	..	1·044	0·95	..	..	1·044	..	..	..	..
Larix	6	1·85	0·90	1·947	1·256+	2·35	1·40	2·475	1·258+	..	..	..	..
decidua	8	2·85	1·00	1·540−	1·386+	3·80	1·45	1·617−	1·346+	..	..	..	..
Mill.	10	3·70	0·85	1·298−	1·630+	4·90	1·10	1·290−	1·522+	..	..	..	..
	12	4·70	1·00	1·270−	1·834+	5·85	0·95	1·194−	1·730+	..	..	..	..
	14	5·45	0·75	1·160−	1·872+	6·75	0·90	1·154−	1·814+	..	..	..	..
	16	6·05	0·60	1·110−	2·192+	7·65	0·90	1·134−	2·096+	..	..	..	..
	18	6·90	0·85	1·141+	2·006−	8·75	1·10	1·144+	2·052−	..	..	..	..
	20	7·55	0·65	1·094−	2·250+	10·10	1·35	1·155+	1·990−	..	..	..	..
	22	8·25	0·70	1·093−	2·356+	11·20	1·10	1·109−	2·120+	..	..	..	..
	24	8·90	0·65	1·079−	2·440+	11·90	0·70	1·063−	2·437+	..	..	..	..
	26	9·40	0·50	1·056−	2·576+	12·60	0·70	1·059−	2·514+	..	..	..	..
	28	9·70	0·30	1·032−	2·590+	13·50	0·90	1·072+	2·492−	..	..	..	..
	30	10·30	0·60	1·062+	2·476−	14·65	1·15	1·085+	2·276−	..	..	..	..
	32	10·90	0·60	1·059−	2·284−	15·60	0·95	1·065−	2·402+	..	..	..	..
	34	11·45	0·55	1·051−	2·702+	16·35	0·75	1·048−	2·646+	..	..	..	..
	36	11·90	0·45	1·044−	2·842+	17·05	0·70	1·043−	2·774+	..	..	..	..

JL 71	2	0·50	0·50	..	1·142	0·50	0·50	..	1·158	..	..	..	..
Larix	4	1·50	1·00	3·000	1·636+	1·30	0·80	2·400	1·504+	..	..	..	..
leptolepis	6	2·50	1·00	1·667−	1·818+	2·65	1·35	2·038−	1·706+	..	..	..	..
Gord.	8	3·70	1·20	1·480−	2·040+	4·20	1·55	1·584−	1·920+	..	..	..	..
	10	4·80	1·10	1·298−	2·098+	5·90	1·70	1·405−	1·940+	..	..	..	..
	12	5·80	1·00	1·209−	2·072−	6·95	1·05	1·178−	2·110+	..	..	..	..
	14	6·45	0·65	1·112−	2·244+	7·55	0·60	1·086−	2·436+	..	..	..	..
	16	6·95	0·50	1·078−	2·454+	8·15	0·60	1·080−	2·746+	..	..	..	..
	18	7·85	0·90	1·130+	2·262−	9·10	0·95	1·117+	2·582−	..	..	..	..
	20	8·65	0·80	1·102−	2·192−	10·35	1·25	1·133+	2·212−	..	..	..	..
	22	9·40	0·75	1·087−	2·406+	11·55	1·20	1·160+	2·244+	..	..	..	..
	24	9·90	0·50	1·053−	2·454+	12·50	0·95	1·082−	2·306+	..	..	..	..
	26	10·30	0·40	1·040−	2·628+	13·20	0·70	1·056−	2·594+	..	..	..	..
	28	10·70	0·40	1·039−	2·672+	13·90	0·70	1·053−	2·560−	..	..	..	..
	30	11·75	1·05	1·098+	2·298−	14·25	0·35	1·025−	2·600+	..	..	..	..
	32	12·30	0·55	1·047−	2·644+	14·50	0·25	1·175+	2·742+	..	..	..	..
	34	13·00	0·70	1·057+	2·580−	14·75	0·25	1·172−	2·796+	..	..	..	..
	36	13·95	0·95	1·075+	2·390−	15·15	0·45	1·031−	2·102−	..	..	..	..
HL 81	7	1·70	..	..	1·466	2·00	..	..	1·394	1·30	..	..	1·398
Larix	9	3·00	1·30	1·768	1·570+	3·55	1·55	1·778	1·780+	2·50	1·20	1·925	1·594+
eurolepis	11	4·50	1·50	1·500−	1·602+	4·80	1·25	1·352−	1·906+	3·90	1·40	1·560−	1·674+
Henry	13	5·70	1·20	1·267−	1·740+	5·45	0·65	1·137−	1·966+	5·25	1·35	1·346−	1·774+
	15	6·70	1·00	1·178−	1·775+	6·18	0·73	1·135−	2·010+	6·30	1·05	1·200−	1·866+
	17	7·30	0·60	1·091−	1·952+	6·70	0·52	1·085−	2·142+	6·90	0·60	1·095−	2·066+
	19	8·15	0·85	1·117+	1·973+	7·35	0·65	1·098+	2·073−	7·70	0·80	1·116+	2·034−
	21	8·75	0·60	1·075−	2·096+	7·90	0·55	1·075−	2·167+	8·45	0·75	1·098−	2·162+
	23	9·80	1·05	1·121+	2·184+	8·56	0·66	1·097+	2·108−	9·35	0·90	1·107+	2·136−
	25	10·65	0·85	1·088−	2·153−	9·10	0·54	1·065−	2·246+	10·20	0·85	1·091−	2·196+
	27	11·35	0·70	1·065−	2·301+	9·68	0·58	1·068+	2·247+	10·90	0·70	1·070−	2·360+
	29	12·00	0·65	1·058−	2·414+	10·10	0·42	1·045−	2·470+	11·55	0·65	1·060−	2·338−
	31	12·60	0·60	1·050−	2·530+	10·38	0·28	1·027−	2·515+	12·00	0·45	1·036−	2·386+
	33	13·10	0·50	1·040−	2·656+	10·65	0·27	1·027	2·637+	12·50	0·50	1·042+	2·582+
	35	13·90	0·80	1·060+	2·390−	10·92	0·27	1·026−	2·640+	13·05	0·55	1·044+	2·518−
	37	14·65	0·75	1·053−	2·410+	11·20	0·28	1·024−	2·724+	13·55	0·50	1·038−	2·676+
	39	15·30	0·65	1·045−	2·300−	11·45	0·25	1·021−	2·830+	13·80	0·25	1·019−	2·732+
	41	16·20	0·90	1·060+	2·288−	11·80	0·35	1·030+	2·762−	14·00	0·20	1·015−	2·756+

TABLE II. *Analysis of Variance*

Source of variance	EL 21 S			EL 21 N			JL 71 S		
	Degree of freedom	*Sum of squares*	*Variance ratio*	*Degree of freedom*	*Sum of squares*	*Variance ratio*	*Degree of freedom*	*Sum of squares*	*Variance ratio*
A. Regression of tracheid length (y) on the combined effect of age (z) and ratio r_2/r_1 (x)	2	3·108212	h.s.	2	3·017895	h.s.	2	1·281893	h.s.
B. Regression of y on x alone	1	3·081624	h.s.	1	2·976771	h.s.	1	1·281150	h.s.
C. Regression of y on z alone	1	3·047481	h.s.	1	2·956177	h.s.	1	1·113200	h.s.
D. Variability accounted for by z, in y, when the effect of x has been allowed for	1	0·026588	n.s.	1	0·041124	n.s.	1	0·000743	n.s.
E. Variability accounted for by x, in y, when the effect of z has been allowed for	1	0·060732	4·91 (s)	1	0·061718	5·76 (s)	1	0·168693	h.s.
F. Error (error, mean square)	13	0·158843 (0·012219)	..	13	0·139313 (0·010716)	..	14	0·074791 (0·005342)	..
G. Total	15	3·267055	..	15	3·157208	..	16	1·356684	..

h.s. = highly significant ($P \leqslant 0{\cdot}01$); s = significant ($P \leqslant 0{\cdot}05 > 0{\cdot}01$); n.s. = not significant ($P > 0{\cdot}05$).

TABLE II. *Analysis of Variance* (cont.)

Source of variance	JL 71 N			HL 81 S			HL 81 N			HL 81 W		
	Degree of freedom	*Sum of squares*	*Variance ratio*	*Degree of freedom*	*Sum of squares*	*Variance ratio*	*Degree of freedom*	*Sum of squares*	*Variance ratio*	*Degree of freedom*	*Sum of squares*	*Variance ratio*
A. Regression of tracheid length (y) on the combined effect of age (z) and ratio r_2/r_1 (x)	2	1·709889	h.s.	2	1·491037	h.s.	2	1·578337	h.s.	2	2·081312	h.s.
B. Regression of y on x alone	1	1·706790	h.s.	1	1·453416	h.s.	1	1·522455	h.s.	1	2·078284	h.s.
C. Regression of y on z alone	1	1·503021	h.s.	1	1·434297	h.s.	1	1·561807	h.s.	1	2·047428	h.s.
D. Variability accounted for by z, in y, when the effect of x has been allowed for	1	0·003097	n.s.	1	0·037621	n.s.	1	0·055882	4·98 (s)	1	0·003028	n.s.
E. Variability accounted for by x, in y, when the effect of z has been allowed for	1	0·206868	5·68 (s)	1	0·056746	4·27 (n.s.)	1	0·001653	n.s.	1	0·033884	11·914 (h.s.)
F. Error (error, mean square)	14	0·619135 (0·044223)	..	14	0·185939 (0·013281)	..	14	0·157251 (0·011232)	..	14	0·039812 (0·002824)	..
G. Total	16	2·329024	..	16	1·676976	..	16	1·735588	..	16	2·121124	..

h.s. = highly significant ($P \leqslant 0{\cdot}01$); s = significant ($P \leqslant 0{\cdot}05 > 0{\cdot}01$); n.s. = not significant ($P > 0{\cdot}05$).

TABLE III. *Analysis of Variance for Testing Significance of the Regression y on x and z*

Variance due to	*Degrees of freedom*	*Sum of squares*	*Mean square*	*Variance ratio*
A. Mean regression for 3 disks combined	2	13·359081	6·679541	h.s.
B. Difference between 3 regressions of 3 disks	4	0·877021	0·219255	h.s.
B_1. Difference between 2 regressions EL and JL	2	0·860704	0·430352	h.s.
B_2. Difference between 2 regressions HL and mean EL/JL	2	0·016317	0·008158	n.s.
C. Difference between regressions within disks	8	0·032473	0·004059	n.s.
D. Error	96	1·375084	0·014324	..
E. Total	110	15·643659	..	..

TABLE IV. *Analysis of Variance for Testing Significance of the Regression y on x*

Variance due to	*Degrees of freedom*	*Sum of squares*	*Mean square*	*Variance ratio*
A. Mean regressions for 3 disks combined	1	13·217552	3·217552	h.s.
B. Difference between 3 regressions of 3 disks	2	0·860654	0·430327	h.s.
B_1. Difference between 2 regressions EL and JL	1	0·858261	0·858261	h.s.
B_2. Difference between 2 regressions HL and mean EL/JL	1	0·002393	0·002393	n.s.
C. Difference between regressions within disks	4	0·022284	0·005571	n.s.
D. Error	103	1·543169	0·014982	..
E. Total	110	15·643659	..	..

(ii) From Item B_2, the difference between the regression for the disk HL 81 and the mean regression for the two disks EL 21 and JL 71 combined was not significant. Thus it is probable that the variability of tracheid length of the hybrid larch is between those of its two parents.

2. From Item C, differences between regressions within disks were not significant.

As differences within disks were not significant, and as the tracheid length could be predicted by the ratio r_2/r_1 alone, the independent variate, viz. the age of the tree (z), might be omitted. Thus the regression equation,

$$y = a + bx,$$

was fitted to three disks to predict tracheid length (y) from the ratio r_2/r_1 (x, rectified value of r_2/r_1).

$$\text{EL } 21 : y = 2{\cdot}957 - 1{\cdot}205x.$$
$$\text{JL } 71 : y = 2{\cdot}761 - 0{\cdot}638x.$$
$$\text{HL } 81 : y = 2{\cdot}659 - 0{\cdot}805x.$$

The predicted values of tracheid length which were calculated from the above three regression equations of y on x are shown in solid lines in Fig. 1. The figure shows clearly that the tracheid length/ratio r_2/r_1 curve of HL 81 is intermediate between the corresponding curves of the disks EL 21 and JL 71.

DISCUSSION.

Tracheid length and ratio r_2/r_1. The evidence given above has shown that the pattern of variation in tracheid length from pith outwards in the stem of larch trees agrees with the law which was established by Sanio (12) and was modified by Bailey and Tupper (3), namely, the average length of the tracheids increases from the pith outwards for a period of years, and then fluctuates more or less in subsequent years. The data show also that the variation in average tracheid length is highly significantly correlated with the ratio r_2/r_1, i.e. when the value of the ratio r_2/r_1 tends to decrease from one period of time to another, the average tracheid length tends to increase, and vice versa. Naturally the question arises, why does the tracheid length vary inversely with the value of the ratio r_2/r_1? In order to answer this question, it is desirable to go back to the variability in size of the cambial initials. According to Bailey (1) it is possible to use tracheid length as an index of the approximate length of the fusiform initials, subject to an error of 5 to 10 per cent. Therefore the variation in tracheid length from the pith outwards may be regarded as similar to the variation in length of the fusiform initials from year to year.

It has been stated by Priestley (11) that when the new shoot ceases growth in height, the cambium layer in that segment of the shoot will not move vertically. When, therefore, the radial growth of that portion of the stem increases year after year, the cambium layer has to increase in perimeter. According to a computation made by Bailey (2), based on his study of *Pinus strobus* L., the cambium must increase in length of perimeter largely through the addition of new fusiform initials. Bailey's work (2) shows also that the newly formed daughter fusiform initials are much shorter than the mother initials from which they have been derived.

It may be inferred that in a segment of cambium the numerous fusiform initials are of various developmental stages, ranging from the newly formed ones to those which have attained the final size and are going to divide into daughter initials. The distribution of stages of these initials is probably asymmetrical, i.e. if the rapidity of the tangential pseudo-transverse cell division is accelerated by the effect of certain stimuli, there will be a large proportion of newer generations of initials in the cambium; if the rapidity is retarded, the older generations of initials will predominate; and in the former case the average length of initials will tend

to decrease; whilst in the latter case the average size of initials will tend to increase. In other words, the percentage of new fusiform initials (number of new initials expressed as a percentage of the total number of initials) added to the cambium determines the average size. Thus the variation in average length of fusiform initials from one given period of time to another will be inversely proportional to the corresponding variation in percentage of new initials in the cambium. The latter, in turn, will be directly proportional to the variation in the increase in perimeter of the cambium as a percentage of the previous perimeter (simply, percentage increment of perimeter), i.e. if the percentage increment of perimeter increases, the average length of fusiform initials will decrease; if the percentage increment of perimeter decreases, the average length of fusiform initials will correspondingly increase. The same relationship will hold true between the percentage increment of perimeter and tracheid length. It will be noted that this percentage increment of perimeter is directly proportional to the ratio r_2/r_1.[1] Therefore the tracheid length will be negatively correlated to the ratio r_2/r_1 as already demonstrated from the regression equations (pp. 224–5).

Tracheid length and age. From near the pith, outwards, the percentage increment of perimeter tends to decrease, hence age or ring number appears to be the controlling factor of the tracheid length. Actually, some investigators have attempted to establish such a relationship. For instance, Kribs (9) showed a linear correlation between age and tracheid length, which was more or less confirmed by Bethel (4). However, if the trees that they examined had been old enough, they would have noticed the fluctuation of the tracheid length (1, 3, 7, 10, 13), which could not be explained by the effect of age. The three disks used in this study were not old enough either; this explains why a highly significant connexion has been found between ring number and tracheid length. But the analyses showed that the ratio r_2/r_1 had a much greater effect than the ring number. The effect of age is only the result of its effect on the percentage increment of the perimeter.

Difference between three disks. Fig. 1 shows clearly that the variability of tracheid length of the disk EL 21 differed very much from that of the disk JL 71, whilst the disk HL 81 was intermediate. During the young stage (near the pith) tracheids of EL 21 were shorter than those of JL 71; but in later years, as the ratio r_2/r_1 decreased, the increase in the tracheid length of EL 21 was more rapid than in the case of JL 71. For the reason already stated above it may be inferred that as a result of a given increase in percentage increment of perimeter of cambium, the frequency of cell division from mother fusiform initials

[1] Let the radius of stem at a given height be r_1 at the beginning of a given period, with its perimeter $2\pi r_1$; let the radius at the end of that period be r_2, with a perimeter $2\pi r_2$. Then the rate of increment of perimeter is $2\pi(r_2-r_1)$; the latter, when expressed as a percentage of the previous perimeter $2\pi r_1$, is $\frac{2\pi(r_2-r_1)}{2\pi r_1}$ 100, and is termed percentage increment of perimeter. Since

$$\frac{2\pi(r_2-r_1)}{2\pi r_1}100 = \frac{r_2-r_1}{r_1}100 = \left(\frac{r_2}{r_1}-1\right)100,$$

the percentage increment of perimeter is directly proportional to the ratio r_2/r_1.

into daughter initials in the cambium of the European larch disk was less than in the case of the Japanese larch disk; thus the average length of fusiform initials of the EL 21 disk tended to be greater. As these three disks were from three species, there is the possibility that the above-stated differences may be characteristic of the species.

SUMMARY.

1. In the stem wood of the genus *Larix*, tracheid length at a given height increased from the pith outwards through a number of rings, and then fluctuated.

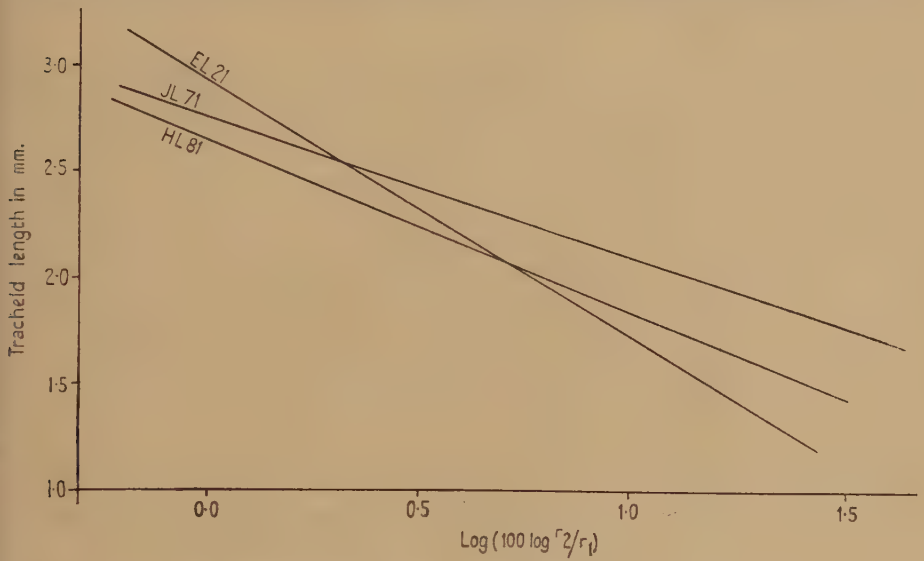

FIG. 1. Relationship between tracheid length and the ratio r_2/r_1.

2. The above variation in tracheid length was dependent on the percentage increment of perimeter; the latter, in turn, was indicated by the ratio r_2/r_1, where r_2 was the radius from the pith to an outer ring, and r_1, the radius from the pith to an inner ring. The tracheid length was negatively correlated with the ratio r_2/r_1.

3. There was also a significant correlation between tracheid length and the age of the tree (indicated by the number of rings from the pith). However, if the age of the tree is used as the factor to predict the tracheid length, a significantly improved prediction will be obtained by taking the ratio r_2/r_1 into account. If the ratio r_2/r_1 is used as the factor to predict the tracheid length, the improvement in prediction as a result of taking the age of the tree into account as well will not be significant.

4. The regression of tracheid length on the ratio r_2/r_1 may be a distinguishing characteristic of each of the three species, European larch, Japanese larch, and hybrid larch (*Larix decidua* Mill., *L. leptolepis* Gord., *L. eurolepis* Henry).

(*See also the Note below.*)

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NOTE

General Patterns of Variation in Xylary Features investigated in the Thesis entitled 'The Study of Wood Anatomy within the Genus Larix, *and the Influence of Internal and External Factors thereon'*

The preceding article is an account of part of the above-named thesis. Besides the variation in tracheid length from the pith outwards at a given tree height, other anatomical features, such as tracheid length and width, height of rays, ring width, distribution and diameter of resin ducts, &c., were investigated from the top to the base of the stem within a given year's ring. The material consisted of eleven trees, of which one was Japanese larch (*Larix leptolepis* Gord.), seven were European larch (*Larix decidua* Mill.), and two hybrid larch (*Larix eurolepis* Henry). A brief description of the general patterns of variation in these xylary features is given in this note. Owing to the considerable length and complexity of the investigation, it has not been practicable to give here the regression equations and statistical analyses on which the conclusions are based, or to condense the hypothesis which has been suggested in the thesis to explain the results obtained.

PATTERN OF VARIATION IN TRACHEID LENGTH, ETC.

Tracheid length. It has been shown in the thesis that the average tracheid length of the eleven larch trees investigated increases within the 1944 year ring from the top of the stem downwards, first rapidly, then slowly, until it reaches a maximum at about 20 per cent. tree height from the ground; thence it decreases towards the base of the stem.

Number of tracheids per unit tangential length (or inversely, tangential width of tracheid.) It has been shown also that the number of tracheids per unit length along a given tangential line on the cross-section of the 1944 year ring is greatest at the top of the tree; it decreases thence along the stem, downwards, until a minimum is reached at about 20 per cent. tree height from the ground; it then increases towards the basal part. Inversely, the tangential width of tracheids increases from the top of the stem downwards to the lower part, and then decreases.

Number of rays per unit tangential length (or inversely average tangential space between two rays). It has been demonstrated in the thesis that the number of rays per unit tangential length decreases within the 1944 year ring from the top of the stem downwards until it reaches a minimum at about 20 per cent. tree height from the ground; thence it increases towards the basal part. Inversely, the average tangential space between two neighbouring rays increases from the top of the stem downwards to 20 per cent. tree height, and then decreases.

Number of horizontal resin ducts per unit area. It has been shown also that the number of horizontal resin ducts per unit tangential area within the 1944 year ring is greatest at the top of the stem; it decreases from there downwards, until the minimum value is reached at about 30 per cent. tree height from the ground; and then it increases towards the basal part.

Number of vertical resin ducts per unit area. The general pattern of variation in number of vertical resin ducts per unit cross-sectional area within the 1944 year ring from the top of the stem downwards is not so clear. Nevertheless, it may be postulated that this variation tends to follow the same pattern ascribed to the variation in number of horizontal ducts.

Rate of local taper. The 'rate of local taper', as defined in the original thesis, is the ratio:

$$\frac{\text{The radius of the stem from the pith to the given year's ring at a lower position}}{\text{The radius of the stem from the pith to the given year's ring at a higher position}}.$$

It has been shown in the thesis that the 'rate of local taper' decreases from the top of the stem downwards, first rapidly and then slowly, until a minimum has been reached at about 20 per cent. tree height from the ground; thence it increases towards the base of the stem.

Relationships. A comparison of the above patterns discloses that they are similar to each other. In other words, all these patterns are either directly or inversely similar to the pattern of variation in the 'rate of local taper'. The 'rate of local taper', although it is not an item of xylary structure, is easy to measure. Consequently, the 'rate of local taper' may be used to predict the variations in the above xylary structures. For instance, if the 'rate of local taper' increases from a higher to a lower position along the stem, it may be expected that within the outermost ring and from the same higher to the same lower position, the average tracheid length, the average tangential width of tracheids, and the average tangential space between two neighbouring rays, will decrease; whilst the average number of resin ducts (either vertical ducts or horizontal ducts) will increase; and vice versa.

The above-stated relationships between the 'rate of local taper' and any of these variations in xylary features have been tested by analyses of variance and shown to be significant. However, it has also been shown that when the 'rate of local taper' has been taken into account for predicting the variations in tracheid length, in number of tracheids per unit tangential length, and in number of resin ducts (either vertical or horizontal) per unit area, the predictions can be improved by taking the polynomial series of per cent. tree height into account as well. The variation in number of rays per unit tangential length is an exception; in that case, the prediction by using the 'rate of local taper' as the sole criterion is sufficient.

It has been shown in the thesis that both the 'ratio r_2/r_1' (see p. 223) and the 'rate of local taper' are the measure of the 'percentage increment of perimeter' (p. 232). Namely, the 'ratio r_2/r_1' measures the 'percentage increment of perimeter' from the pith outwards at the same tree height, and the 'rate of local taper' measures the 'percentage increment of perimeter' within a given ring at different heights. Since the average tracheid length is negatively correlated to the 'ratio r_2/r_1', as demonstrated in this article, it should be, and as a fact is, negatively correlated to the 'rate of local taper'. It may be postulated also that if the variations in number of tracheids per unit tangential length, number of rays per unit tangential length, and number of resin ducts (either vertical or horizontal) per unit area were observed from the pith outwards at a given tree height, they would be positively correlated to the 'ratio r_2/r_1'.

PATTERN OF VARIATION IN RING WIDTH, ETC.

Ring width. It is shown in the thesis that the average width of the 1944 year ring (also the early-wood width) of the eleven larch trees increases from naught at the very top of the stem downwards, and rapidly reaches a maximum at about 85 per cent. tree height from the ground; thence it decreases downwards until at about 10–20 per cent. tree height; thence it increases again towards the base.

Number of epithelial cells per horizontal resin duct (viewed on the tangential section). It has been shown also that the average number of epithelial cells per horizontal resin duct increases within the 1944 year ring from the top of the stem downwards; it reaches a maximum at about 50–60 per cent. tree height from the ground, and decreases thence until a minimum is reached at about 25 per cent. tree height; then it increases again towards the basal part of the stem.

Diameter of horizontal resin ducts. The average diameter of horizontal resin ducts increases within the 1944 year ring from the top of the stem downwards; it reaches a maximum at about 60 per cent. tree height from the ground, thence it decreases until at about 20 per cent. tree height where the diameter of duct is the least; and from there it increases once again towards the base.

Diameter of vertical resin ducts. The pattern of variation in the average diameter of vertical resin ducts within the 1944 year ring and at various heights along the stem of the eleven larch trees is not so clear as above. However, it may be postulated that this variation tends to follow the pattern ascribed to the variation in diameter of horizontal ducts.

Relationships. A comparison of the above patterns shows that they are similar to each other. Since the ring width is easy to measure, it can be used as the criterion to indicate the variations in number of epithelial cells per horizontal duct, and the average diameters of both kinds of resin ducts.

However, it has been found that when the 'ring width' has been taken into account for predicting the variation in number of epithelial cells per horizontal duct, or for predicting the variation in diameter of either kind of resin duct, the prediction will be improved by taking the polynomial series of 'per cent. tree height from the ground' into account as well. The variation in 'ring width' is also related to the polynomial series of 'per cent. tree height from the ground', as well as to its distance from the pith.

The resemblance of the pattern of variation in diameter of horizontal resin ducts to that in number of epithelial cells per horizontal duct indicates a close connexion between these two anatomical features. So far as these eleven larch trees are concerned the average diameter of the horizontal resin duct is approximately equal to $2{\cdot}42 \times$ number of epithelial cells per duct (in microns).

WHERE NO PATTERN IS RECOGNIZABLE.

The variation in average height of uniseriate rays, and average height of fusiform rays, when traced within the 1944 year ring from the top of the stem downwards, may follow a certain trend in one stem and a contrary trend in another. Thus when the eleven larch trees combined are considered, this variation in ray height shows no recognizable general pattern. It has been found also that there is no significant general relationship between either ray height and 'the rate of local taper', or ray height and the polynomial series of 'per cent. tree height'.

The author is indebted to Professor H. M. Steven and Dr. E. V. Laing for help during this investigation, and to Mr. M. H. Quenoille for advice on statistical technique.

SOCIETY'S AND OTHER NEWS

EXCURSION AND ANNUAL GENERAL MEETING, 1949

THIS will be held in the south-west Midlands and Welsh Border with headquarters in Hereford from 3rd to 7th October. Tintern State Forest, Garnons (Sir Richard Cottrell), and Huntley Manor (Major C. P. Ackers) will be visited. A circular giving further details and asking for enrolments will be issued as soon as the preliminary arrangements have been completed. The 22nd Annual General Meeting will be held during the Excursion. (The Committee had hoped to hold the Excursion during the last week of September, but this was found to be impracticable on account of an official engagement which would have prevented many members from attending.)

THIRD WORLD FORESTRY CONGRESS, HELSINKI, 1949

THE Society was invited to send a representative to the above, but the Council has decided on account of expense not to accept. As several members are likely to be there in their official capacities, a first-hand report of the proceedings will be available.

ROLL OF MEMBERS

MEMBERS are reminded of the importance of intimating to the Secretary any changes of address or designation, and any promotions, awards, &c., for inclusion in the roll.

IT is regretted that the rise in the cost of printing *Forestry* (approximately 85 per cent. over the 1939 figure) makes it necessary to reduce its size in order to keep within the Society's income. Such items as the extracts from *Forestry Abstracts* must be omitted. It is hoped they have served their purpose by directing attention to this excellent publication of the Commonwealth Forestry Bureau, Oxford.

An adequate flow of valuable articles for *Forestry*, of the longer type, is reaching the Editor. He would welcome more contributions of a shorter type, equally worthy of inclusion, such as those at pp. 62 and 109 of Vol. xxii, No. 1.

HONOURS

THE New Year's Honours List of 1949 included a knighthood for Mr. W. L. Taylor, Commissioner and recently Director-General of the Forestry Commission. The honour to the profession, to the Commission, and to Mr. Taylor is a welcome recognition of the growing importance of forestry in the United Kingdom and of Mr. Taylor's distinguished services.

ANNUAL EXCURSION OF SEPTEMBER 1948
BASED ON LINCOLN

The third post-war excursion was held at Lincoln from 27th to 30th September 1948. About 42 members attended, including two from well-known timber firms in Scotland, who were specially welcome because of their expert knowledge of utilization; and it was regretted that the Oxford School of Forestry was not represented on this occasion, to take part in the discussions. On each of three days private estate woodlands were visited in the morning and State woodlands in the afternoon. A good range of species and problems was seen in both conifers and hardwoods, especially the latter. The late Mr. Ray Bourne was the prime mover and guide in the study of the private forests, and various senior and junior officers of the Forestry Commission in the State forests. Excellent cyclostyled notes on the past history and main features of the woods visited were provided beforehand. The whole arrangements were admirable, and great credit is due to Mr. Bourne, the Directorate of Forestry for England (Forestry Commission), the Eastern Conservancy, Cambridge, and the office-bearers of the Society concerned, particularly Mr. Galloway, for the results of their co-operation.

The first evening of the three full days spent at Lincoln was occupied by the 21st Annual General Meeting of the Society; and on the two following evenings there were technical discussions. At the first of the latter Mr. Bourne was present, as indeed he was, in the field, on each of the three mornings in the private woodlands. His exceptional courage and spirit in face of extreme physical weakness and disability (he died on 30th Nov.) were an inspiration.

At the discussion on 29th September one speaker after another, many of them old pupils of Mr. Bourne at Oxford, some now in private forestry and some in State forestry, acknowledged the debt they owed to him and the great work he had done for English forestry. He was obviously moved by these tributes and glad that his ideas and work were appreciated and likely to be followed up. (About a fortnight before his death, in still greater weakness, he dictated the substance of an article for *Forestry*, on a type of silviculture he considered specially important. This material is being written up by a friend and will appear in due course.)

Space permits only an outline of what was seen and discussed on the Excursion.

Mr. Bourne demonstrated and explained the following major points in his handling of private estate forestry in the type of woods concerned.

(1) The need for a forestry adviser to rouse the landowner's interest in forestry, to keep down early costs, and to get good intermediate returns from the estate.
(2) The forester must control the game, especially rabbits, *with* the gamekeeper; but the control must be by the forester, and not indirect.
(3) All available natural regeneration should be used.
(4) Crops should be treated on their merits, by sub-compartments, rather than generally under a silvicultural system. The first time round one should mark for felling on a silvicultural basis. Then make rapid periodical enumerations, and local volume tables; and as soon as possible regulate the fellings by volume, based on capital and increment, after the worst of the stock has been removed.
(5) One should work largely on advance growth or the signs of it, and avoid opening the canopy till natural regeneration is appearing on the ground.

(6) Mixed crops, made up of pure groups, are preferable to pure crops.
(7) The marking officer should have, above all, a knowledge of utilization values and fair piece-work rates.

By the courtesy of Magdalen College, Oxford, Lt.-Col. Sir Edmund Bacon, Bt., O.B.E., and the Rt. Hon. the Earl of Manvers, M.C., their woodlands at Girsby Manor, Thonock, and Thoresby (part of Sherwood Forest) were visited, in Lincolnshire and Nottinghamshire. By the courtesy of the Forestry Commission, their forests of Bardney (Birch and Southrey Woods), Laughton, and Clipstone (Whitwell Wood) were visited, in Lincolnshire and Derbyshire. In the private woods the treatment commended by Mr. Bourne was seen in application to oak, wych elm, ash, sycamore, beech, birch, and conifers. Where necessary he was supplementing natural regeneration by planting, but wherever possible he relied on the former, to reduce immediate costs. His choice of oak and his method of dibbling in acorns were criticized by some who would have preferred beech or transplanting oak from rough local nurseries. However, Mr. Bourne said he was quite ready to use beech wherever it seemed better, and that he intended to let the acorns take their chance, without expensive tending.

In the State forests the value of conifer nurses in protecting and bringing through oak and other hardwoods was well seen; also the value of special fire-protection and extraction facilities in difficult country (Laughton); and finally the special difficulties where frost and industrial fumes work against hardwoods, as in Whitwell Wood, about four miles west of the manufacturing town of Worksop.

In the evening technical discussions there was unanimous agreement that the rabbit was a chief obstacle and cause of expense in British forestry, because of the damage it does and the cost of fencing against it. Difficulties were foreseen in getting for State forests the type of marking officer used successfully by Mr. Bourne, at least until a cadre of experienced men has been built up. Also the Forestry Commission had not found mixed crops easy to manage, so far, though they might change their minds on that point presently. Some members expressed doubt on the suitability of some of the areas seen for growing oak, and the financial justification for such a slow crop, in comparison with conifers. Mining for coal was altering the water-table and drainage in some oak forests; and there was some evidence of a major slowing down of the rate of growth, coinciding with disturbance by coal-mining. Other members supported the growing of oak, especially if good quality were attainable.

The frank exchange of divergent views was in the best traditions of free speech and ideas; and it appeared that some at least of the divergences were due to the very different financial and other conditions under which private and State foresters work.

The consensus of opinion was that the 1948 excursion and discussions had been particularly interesting and practical.

In Vol. xxii, No. 1, 1948, in the article on Frost Damage to Sitka Spruce it is regretted that acknowledgement was omitted to the Director, Forest Products Research Laboratory, Princes Risborough, for the photographs of Figs. 1 and 2, facing p. 62.

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